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**Apollo 15's record-breaking astronaut**
**AL WORDEN, NASA PILOT**

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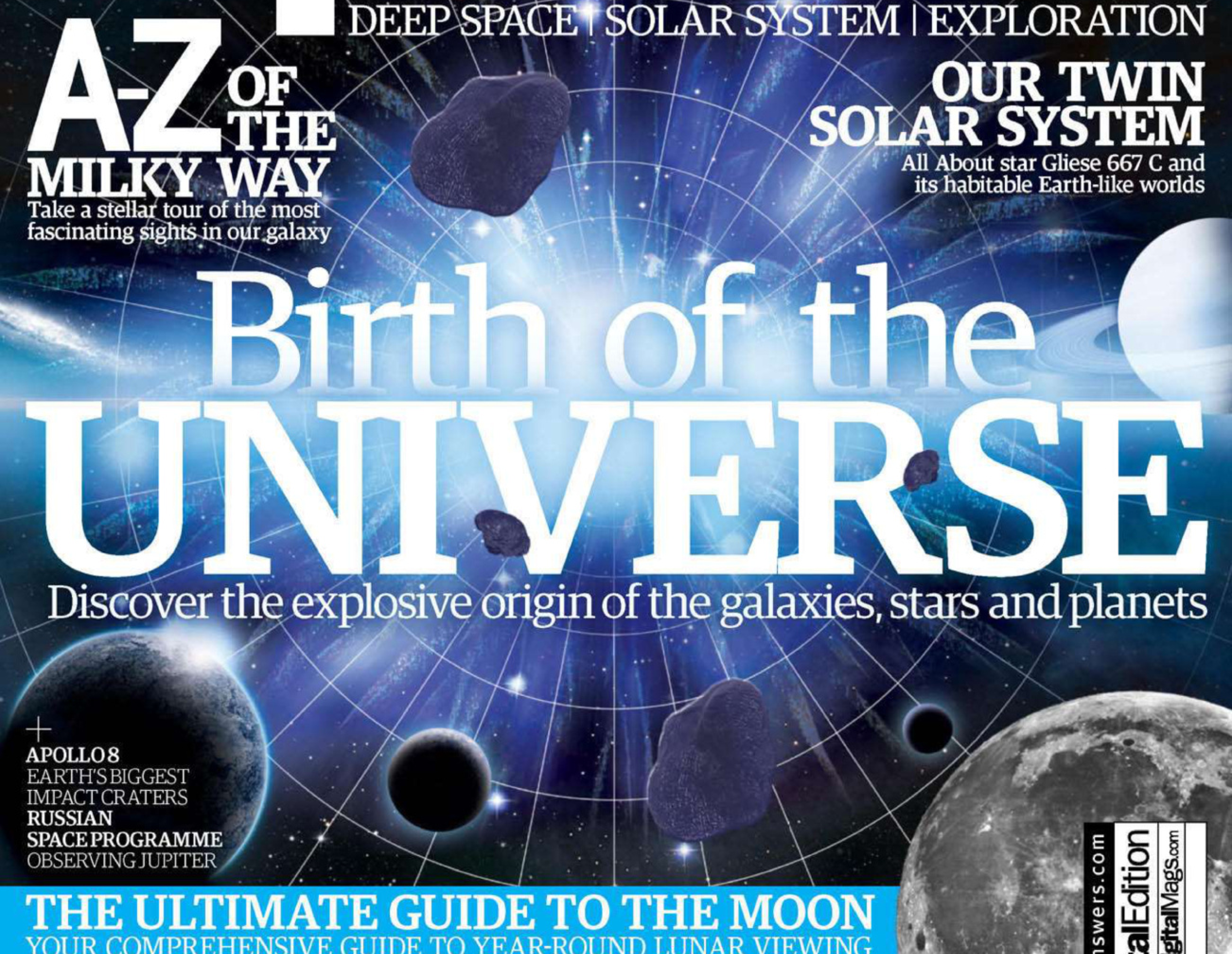
DEEP SPACE | SOLAR SYSTEM | EXPLORATION



## A-Z OF THE MILKY WAY

Take a stellar tour of the most fascinating sights in our galaxy

## OUR TWIN SOLAR SYSTEM

All About star Gliese 667 C and its habitable Earth-like worlds

# Birth of the UNIVERSE

Discover the explosive origin of the galaxies, stars and planets

+
**APOLLO 8**
EARTH'S BIGGEST IMPACT CRATERS
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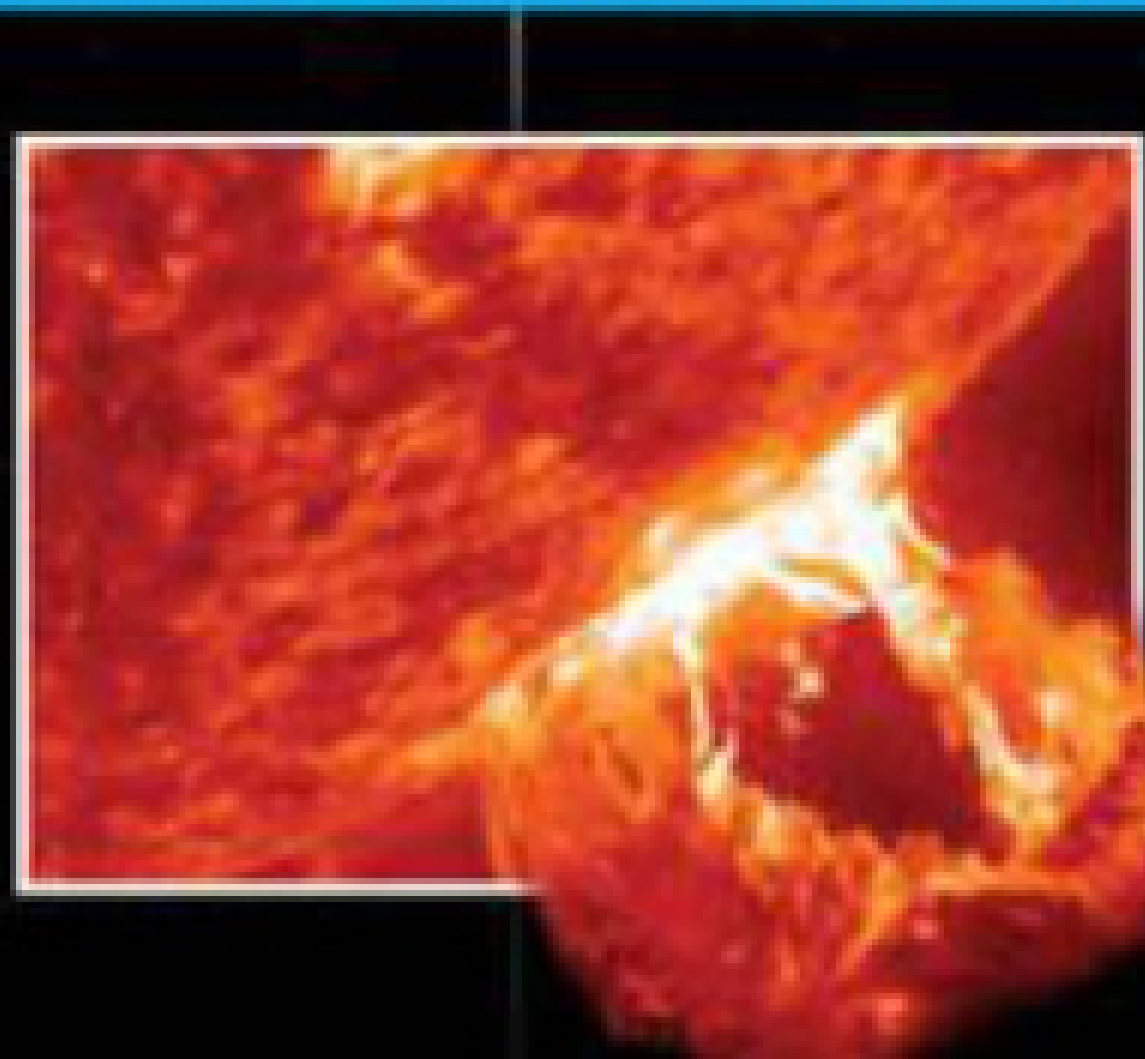
## THE ULTIMATE GUIDE TO THE MOON

YOUR COMPREHENSIVE GUIDE TO YEAR-ROUND LUNAR VIEWING

## ARTIFICIAL GRAVITY SHIP

On board the ultra-futuristic deep space craft, Nautilus-X



## SOLAR FLARES

Amazing facts about these searing outbursts

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# Blast off into a universe of knowledge

It's when you begin to investigate the theories that surround the origins of our universe that you start to see the lines between the space sciences, physics and mathematics blur: figures that would make the energy output of the most massive quasar seem like a candle next to the Sun, are bandied about like simple arithmetic in a primary school classroom. Mind-boggling existential concepts of multiple universes, infinite time and space are made to seem as mundane as the idea of going in to work tomorrow. Luckily we had three Big Bang experts on hand, who deal with this theory and its myriad of complexities on a daily basis, to break down this fascinating but hard-to-swallow subject into more palatable pieces. But our new insight into the world of bosons, quarks, cosmic expansion and the formation of proto-galaxies does give us a glimpse into what it might have been like to study space during the Renaissance, when the natural sciences, philosophy and astronomy were studied in conjunction with each other.

This issue, we've been lucky enough to speak to a number of other prominent scientists and figureheads in the space community, including Al Worden, Apollo 15's pilot and record-holder for being the astronaut to travel the farthest from Earth. Also, Dr David Kring, the man who helped discover the enormous Chicxulub impact crater on the Yucatán Peninsula, Mexico, then linked it to the extinction of the dinosaurs 65 million years ago. With Jupiter taking a prominent place in the sky and our 'Ultimate guide to the Moon' on page 80, now's a great time to get your telescope out and start stargazing, too. Enjoy!

**Ben Biggs**
Deputy Editor

> "I was further away from the guys on the surface of the Moon than anybody"
>
> **Al Worden, Apollo 15 pilot**

## Crew roster

Jonathan O'Callaghan

■ In preparation for his feature, dedicated method-writer Jonny adopted a thick Russian accent.

Gemma Lavender

■ A true fact: Gemma has never been to the Moon, despite writing our Moon guide.

Laura Mears

■ Laura explains how we're going to bring chunks of rock back from Mars to Earth on page 36.

Shanna Freeman

■ Shanna is obsessed with exoplanets – making her the perfect writer for Gliese 667 C.

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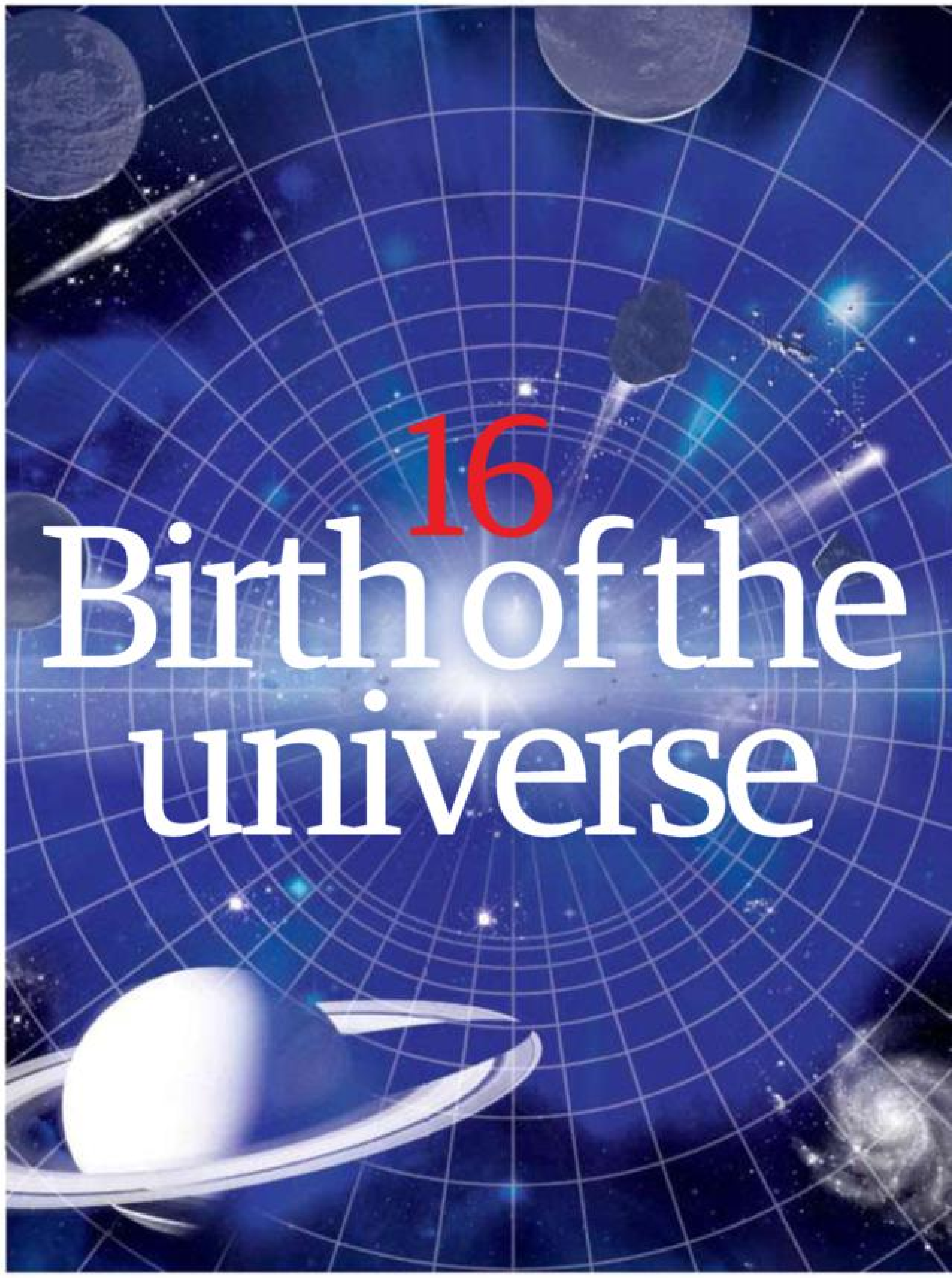

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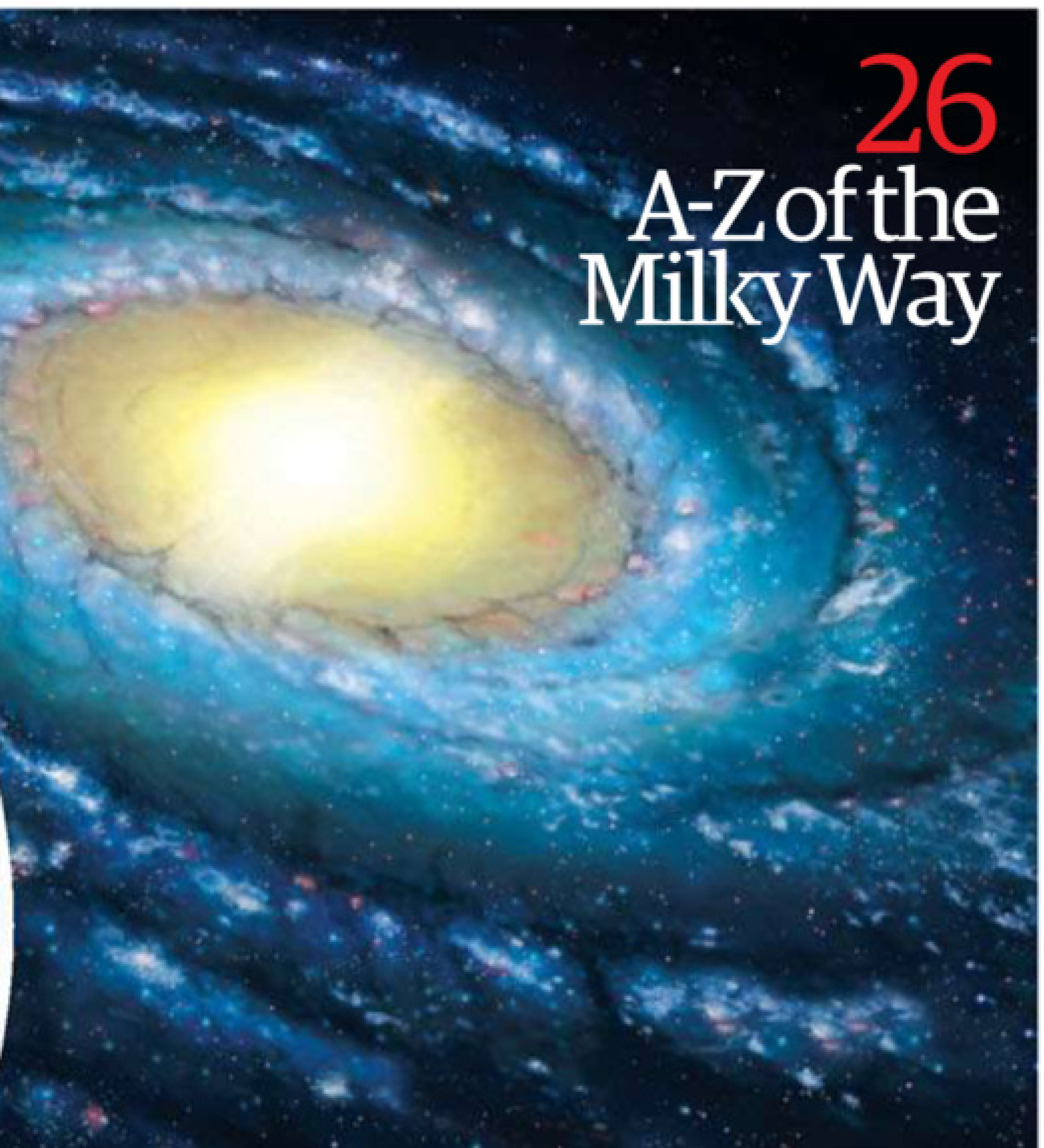

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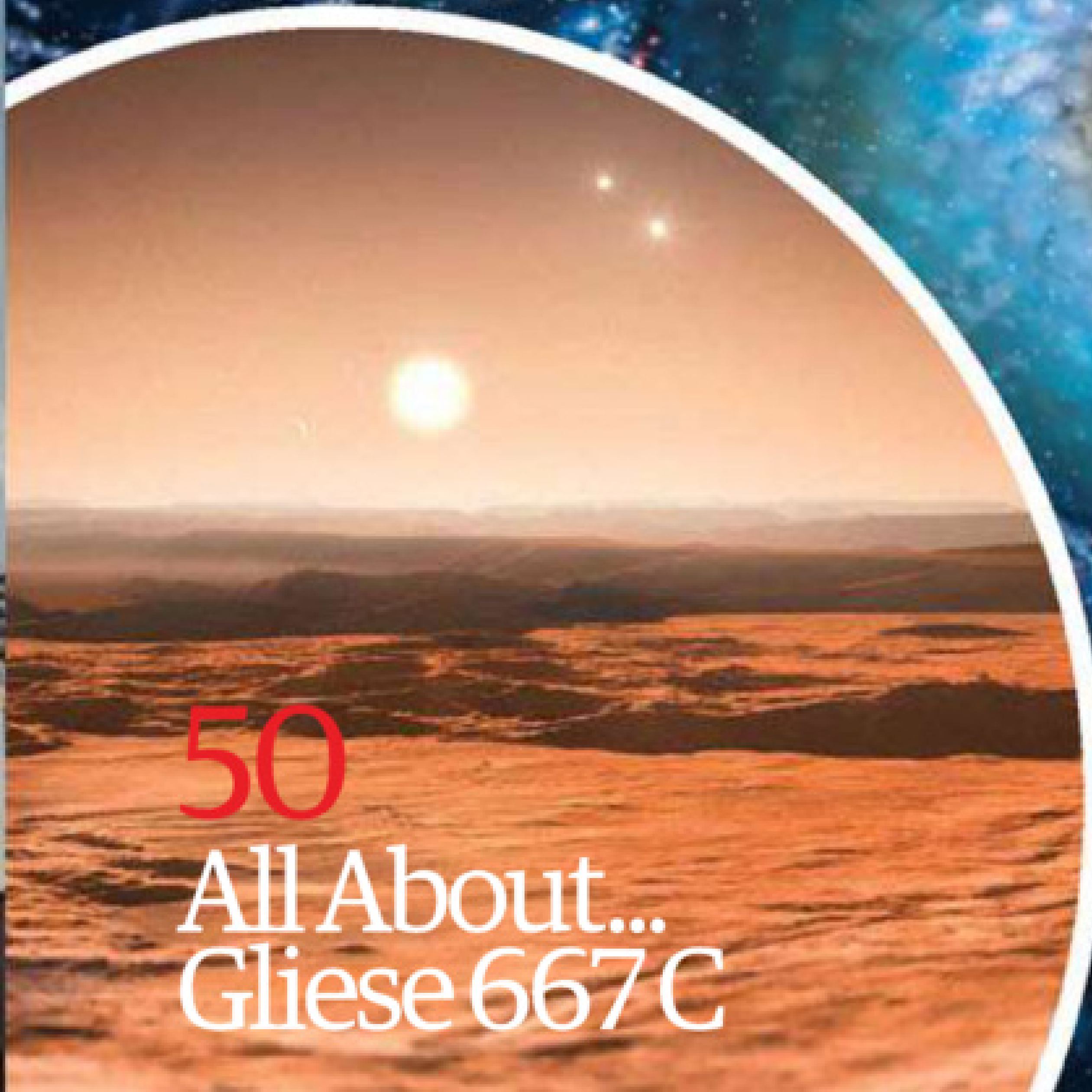

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# LAUNCH PAD

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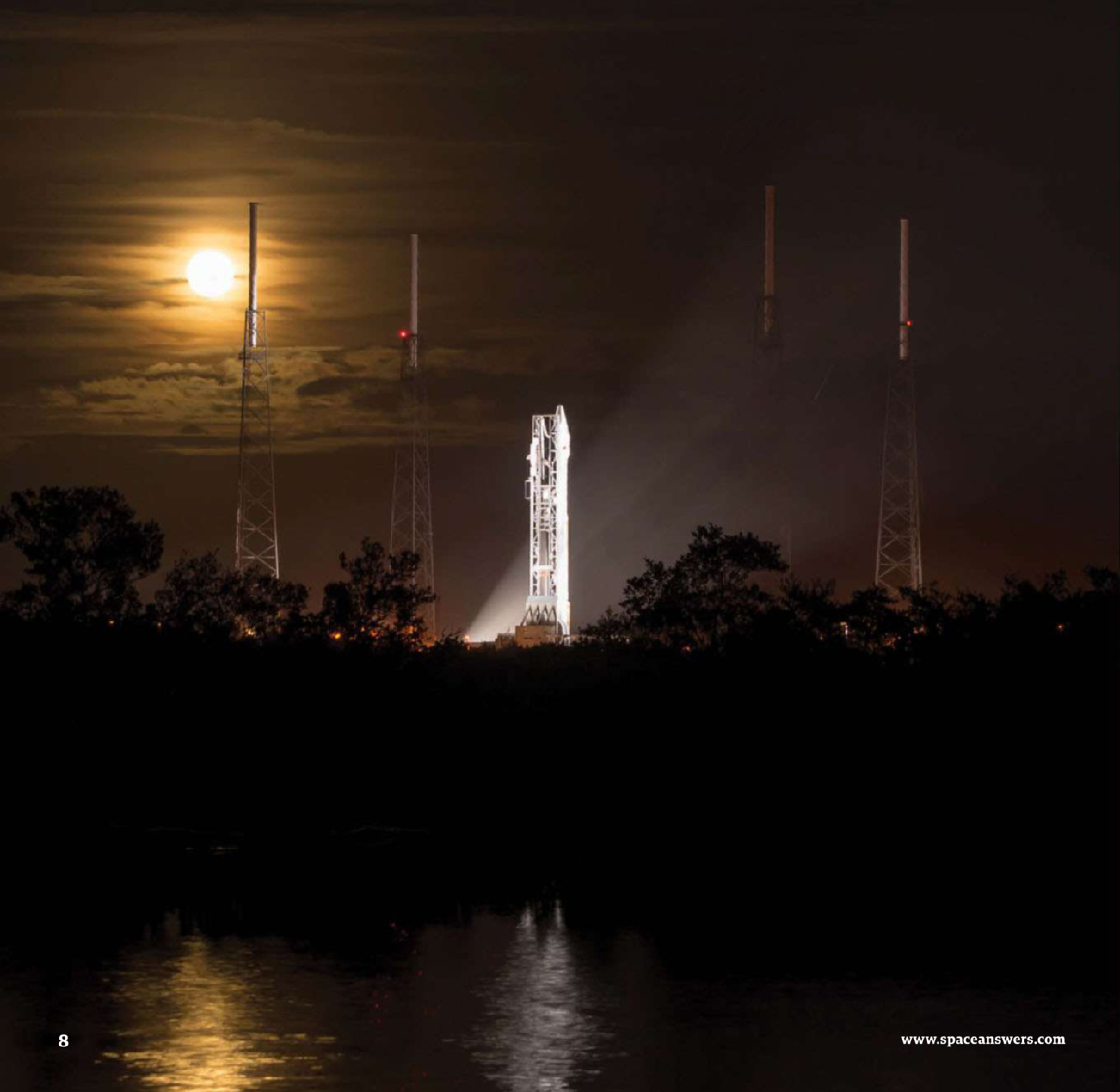
Storemags

# Space bricks

The International Space Station's Kibo laboratory robotic arm deploys three nanosatellites known as Cubesats into low Earth orbit. Expedition 38 flight engineer Koichi Wakata, an astronaut for the Japanese Aerospace Exploration Agency (JAXA), monitored the Cubesats from the module while operating the robotic arm. Cubesats have become increasingly popular within the last ten years as their design has become more standardised and affordable to universities and other institutes.

# The night before launch

It's the evening of Sunday 17 November 2013 at Cape Canaveral Air Force Station, Space Launch Complex 41, and a full Moon beckons a dormant Atlas V rocket with its Mars-bound payload atop. This is of course the much-anticipated MAVEN (Mars Atmosphere and Volatile EvolutioN) mission awaiting its late morning countdown the following day. The MAVEN spacecraft launched successfully on Monday 18 November and by the time you read this, it will have just made its first trajectory correction manoeuvre, making its way towards the Red Planet for Mars orbital insertion on 22 September 2014.



# Fate of ISON

This composite image of 60 frames shot by Sun-watching observatory SOHO (Solar and Heliospheric Observatory) over 28 and 29 November 2013, shows the transformation and fate of Comet ISON as it rounded and moved into perihelion around the Sun. As temperatures increased, chunks of the comet began to break off and it shrank in size, with very little emerging on the other side of the Sun to flee back into space. Astronomers are unsure whether this lump was the remains of the original nucleus or simply debris, but whatever it was is unlikely to be anything more than dust now.

# The anaemic galaxy

If you thought that NGC 4921 was looking a little pastier than your average galaxy, that's because it's anaemic. At least, anaemic in the sense that it produces stars at an unusually low rate and has a low surface brightness. Despite this, Hubble has been imaging the pale galaxy recently because its known speed of recession from the Milky Way coupled with a more precise determination of its distance from Earth (currently estimated at 310 million light years), could help scientists better calibrate the expansion rate of the observable universe.

© NASA; Bill Ingalls

# Water plumes spotted on Europa

## Compelling evidence for a massive subsurface ocean is discovered on the Jovian moon

Water shoots from a vent at -40°C (-40°F) on the moon of Europa, 800 million km (500 million mi) from the Sun

The Hubble Space Telescope has observed plumes of water vapour jetting off the south polar region of Europa. The frigid moon is already thought to harbour a huge subsurface ocean beneath its icy crust, but this is the most compelling evidence yet that this the case, according to Lorenz Roth of the Southwest Research Institute in Texas. "By far the simplest explanation for this water vapour is that it erupted from plumes on the surface of Europa," said Roth.

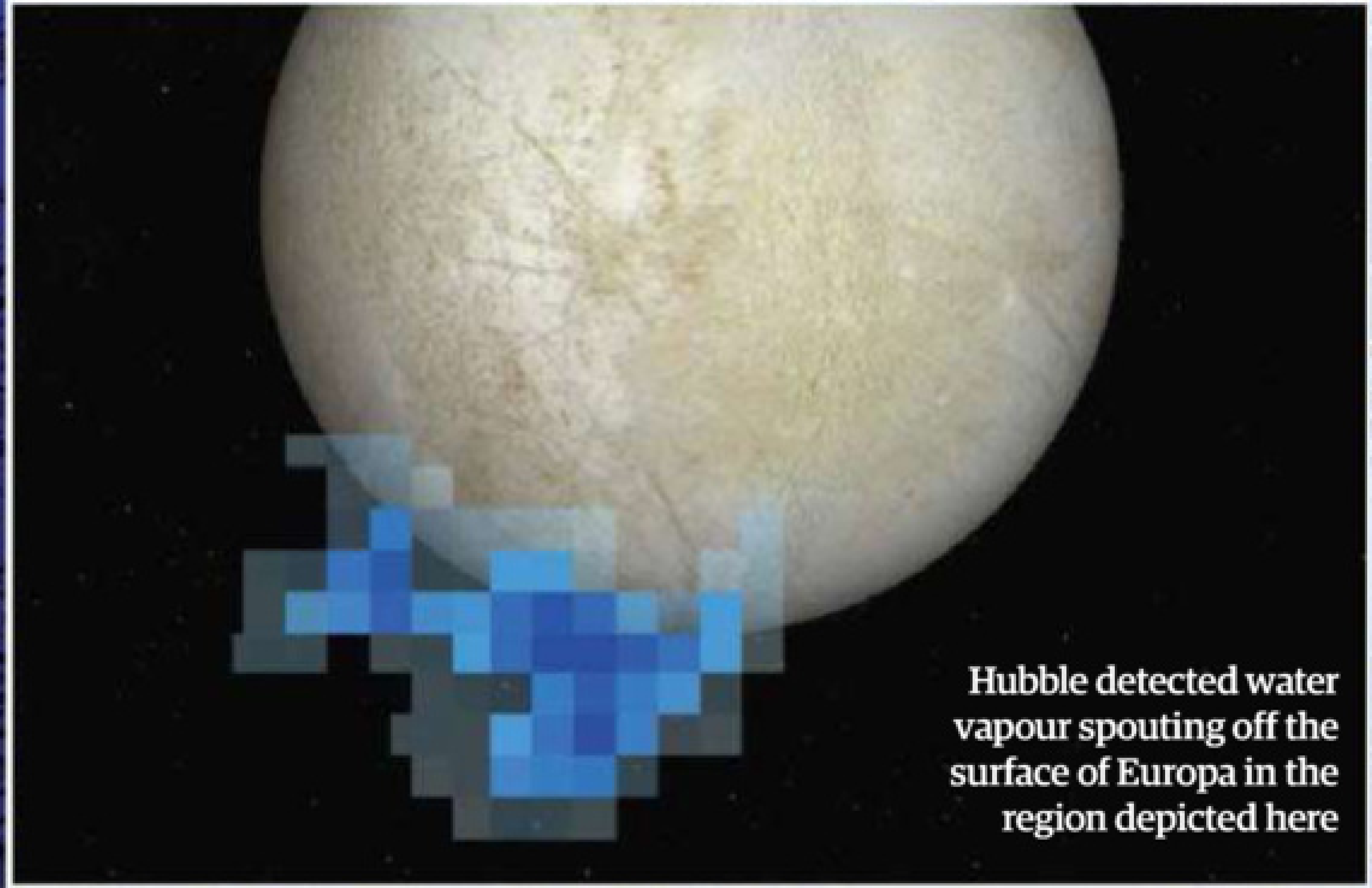
Scientists from the Southwest Research Institute think that if they can directly connect the water plumes to a water ocean they're almost certain exists beneath the surface of Europa, they'll be able to analyse it without having to send a costly mission to drill into the crust.

Using Hubble's imaging spectrograph, scientists were able to see an auroral glow produced when atomic hydrogen and oxygen are excited – the telltale signs of water being broken apart by Jupiter's magnetic field lines. The source of these plumes of water was suggested to be from long cracks running along Europa's surface. "We pushed Hubble to its limits to see this very faint emission," said Joachim Saur, co-author of a paper on the subject and principal investigator at the University of Cologne. "These could be stealth plumes, because they might be tenuous and difficult to observe in the visible light."

Interestingly, these water jets have so far only been observed when the moon of Europa is in the apogee of its elliptical orbit around gas giant Jupiter. This is thought to be because the cracks, or 'lineae', are subjected to greater stresses from gravitational forces, as the vents are tugged open wider to release the jets. This supports a subsurface ocean theory, because the jets wouldn't vary as much at this distance as they do with a more solid interior.

Similar jets of water have also been observed spouting off one of Saturn's moons, Enceladus. Europa has 12 times the gravitational force of Enceladus, so the water vapour doesn't escape into space, instead falling back down to Europa. ■

> "The simplest explanation for this water vapour is that it erupted from plumes on the surface of Europa"
> **Lorenz Roth, Southwest Research Institute**



Hubble detected water vapour spouting off the surface of Europa in the region depicted here

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# First black hole image sought

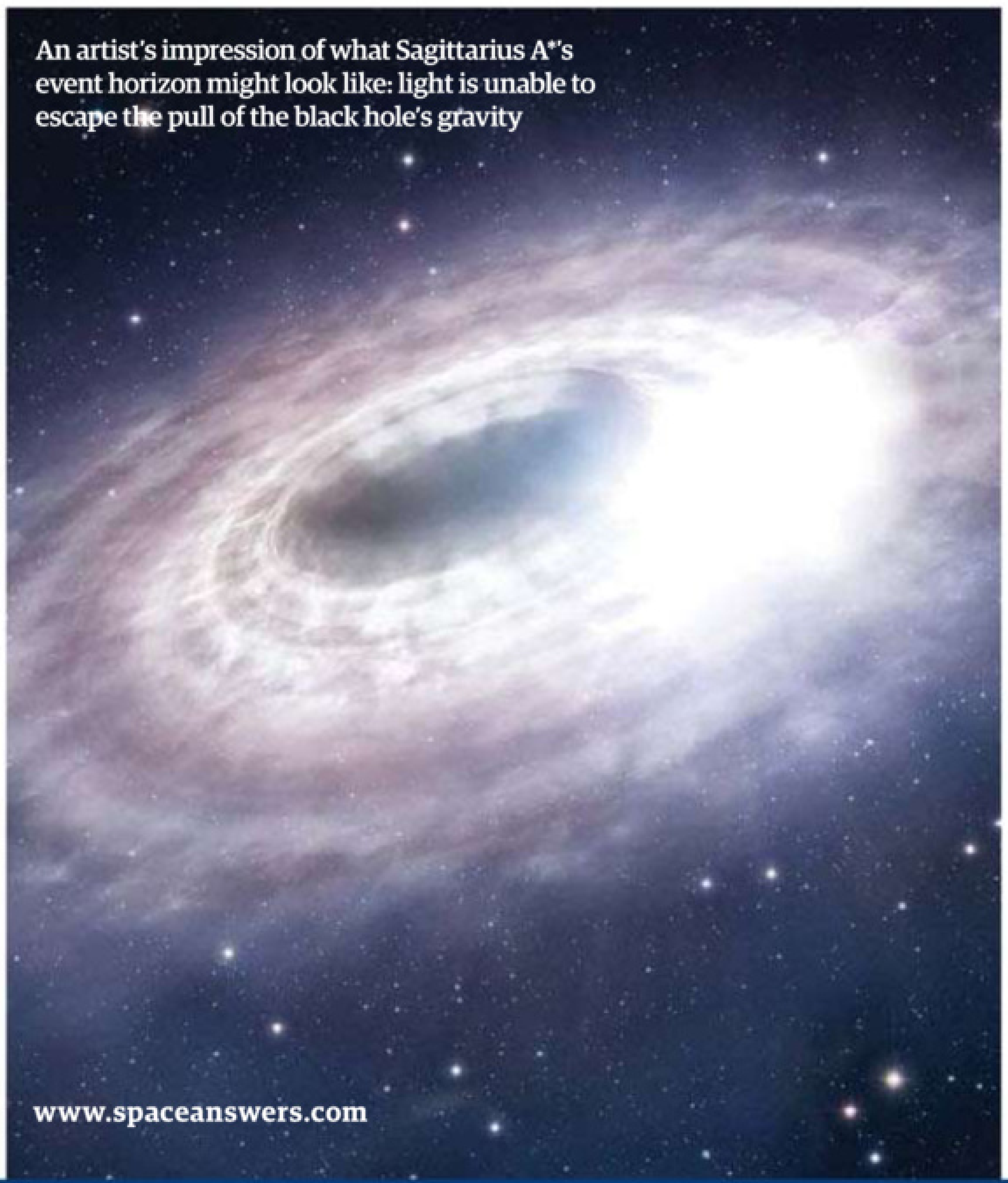
## European astronomers aim to take the world's first shot of a black hole

It's commonly known that it's impossible to see a black hole because nothing can escape its gravity, not even light. But that isn't stopping a team of European astrophysicists from trying to image one: backed by a €14 million grant from the European Research Council, the team is hoping to image the shadow that's cast by the event horizon of Sagittarius A*, the supermassive black hole suspected to be the core of the Milky Way. "While most astrophysicists believe black holes exist," said professor Heino Falcke of Radboud University, Netherlands, "nobody has actually ever seen one. The technology is now advanced enough that we can actually image black holes and check if they truly exist as predicted: if there is no event horizon, there are no black holes."

Looking at the strange radio source at the centre of our galaxy, where the supermassive black hole Sagittarius A* is suspected to reside, is a likely method of imaging its event horizon, if it exists. It's thought the event horizon of an object as massive as this (Sagittarius A* has an estimated mass of 4 million sols) will cast a dark shadow on the radio emissions created by gas falling into the black hole.

By combining high-frequency telescope observations from around the world, the team also hopes to find new pulsars and test theories on the behaviour of light and matter around black holes. ●

> "While most astrophysicists believe black holes exist, nobody has actually ever seen one"



An artist's impression of what Sagittarius A*'s event horizon might look like: light is unable to escape the pull of the black hole's gravity

Dolphin habitats, endangered orangutans, weird Australian wildlife and much, much more

World Of Animals issue two on sale now

From the slovenly sloths of the Amazon to the polar bears of the Arctic Circle, **World Of Animals** is a new monthly magazine from the makers of **How It Works** and **All About History** that takes a unique look at wonderful wildlife from all over the globe.

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**World Of Animals** can be found alongside digital editions for iOS and Android available from greatdigitalmags.com and is accompanied by companion website animalanswers.co.uk. Connect on Twitter @WorldAnimalsMag and Facebook at facebook.com/worldofanimalsmag and let the team know what you would love to see in forthcoming issues of **World Of Animals**. ●

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### 150,000 cosmic rays detected

NASA's Swift satellite has compiled a list of over 150,000 major X-ray sources, including high-energy stars and galaxies. Eight years' worth of data was analysed by the mission's team of scientists, revealing almost 100,000 previously unknown cosmic X-ray sources.

### China lands on the Moon

The Chinese rover Jade Rabbit has landed on the Moon's surface and will operate there for a year. It is the first soft Moon landing since the Soviet space agency landed there in 1976.

### Radiation measured on Mars

The first radiation measurements taken on the surface of Mars have been published. Curiosity has detected two forms of radiation that pose a health risk to astronauts: galactic cosmic rays and solar energetic particles.

### Cosmic tweets confound scientists

Fast radio bursts are radio wave pulses that last only one millisecond. They were thought to come from galaxies billions of light years away. Scientists now think these 'tweets' are created by stellar flares in our galaxy.

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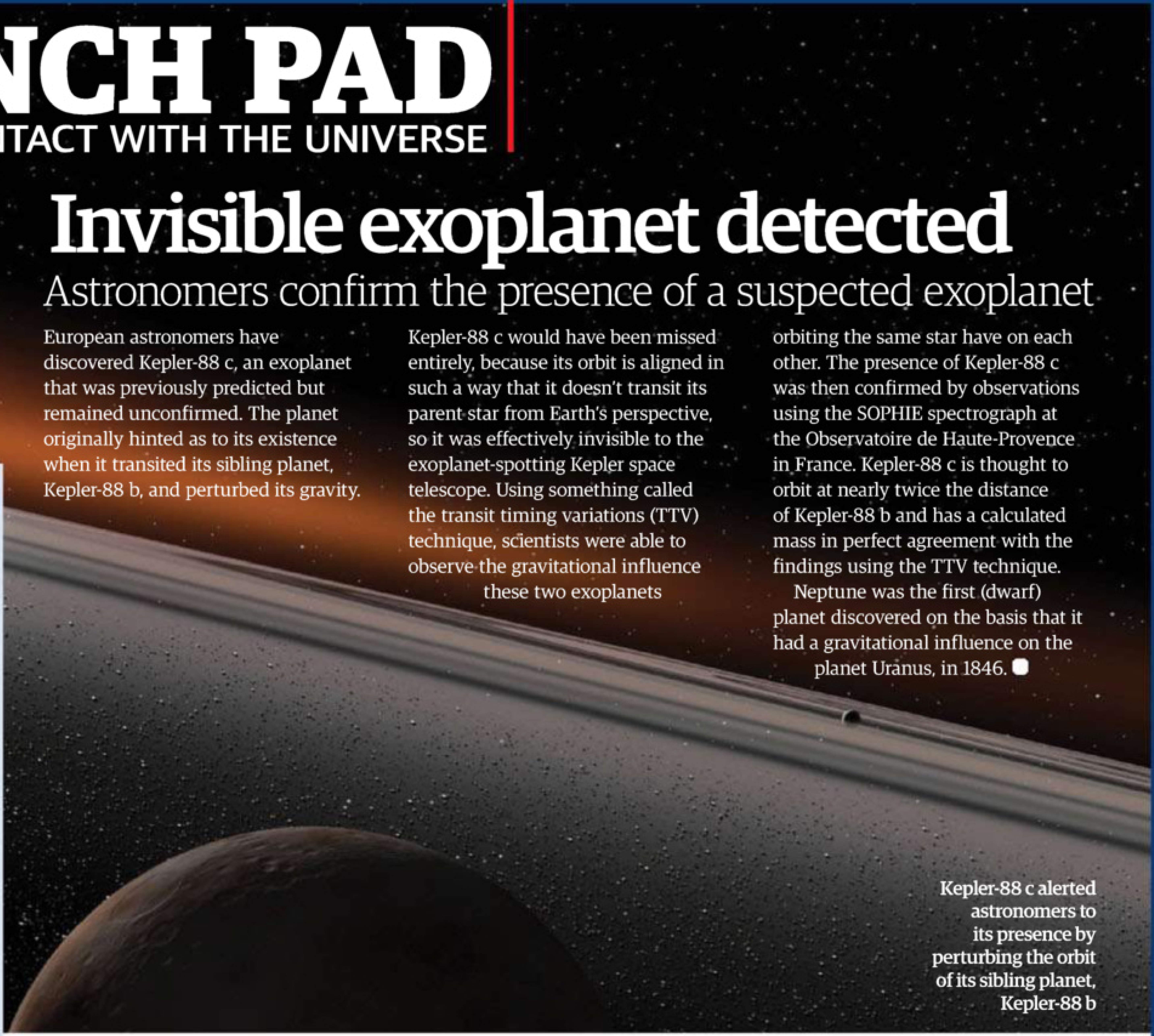
# Invisible exoplanet detected

## Astronomers confirm the presence of a suspected exoplanet

European astronomers have discovered Kepler-88 c, an exoplanet that was previously predicted but remained unconfirmed. The planet originally hinted as to its existence when it transited its sibling planet, Kepler-88 b, and perturbed its gravity. Kepler-88 c would have been missed entirely, because its orbit is aligned in such a way that it doesn't transit its parent star from Earth's perspective, so it was effectively invisible to the exoplanet-spotting Kepler space telescope. Using something called the transit timing variations (TTV) technique, scientists were able to observe the gravitational influence these two exoplanets orbiting the same star have on each other. The presence of Kepler-88 c was then confirmed by observations using the SOPHIE spectrograph at the Observatoire de Haute-Provence in France. Kepler-88 c is thought to orbit at nearly twice the distance of Kepler-88 b and has a calculated mass in perfect agreement with the findings using the TTV technique.

Neptune was the first (dwarf) planet discovered on the basis that it had a gravitational influence on the planet Uranus, in 1846.



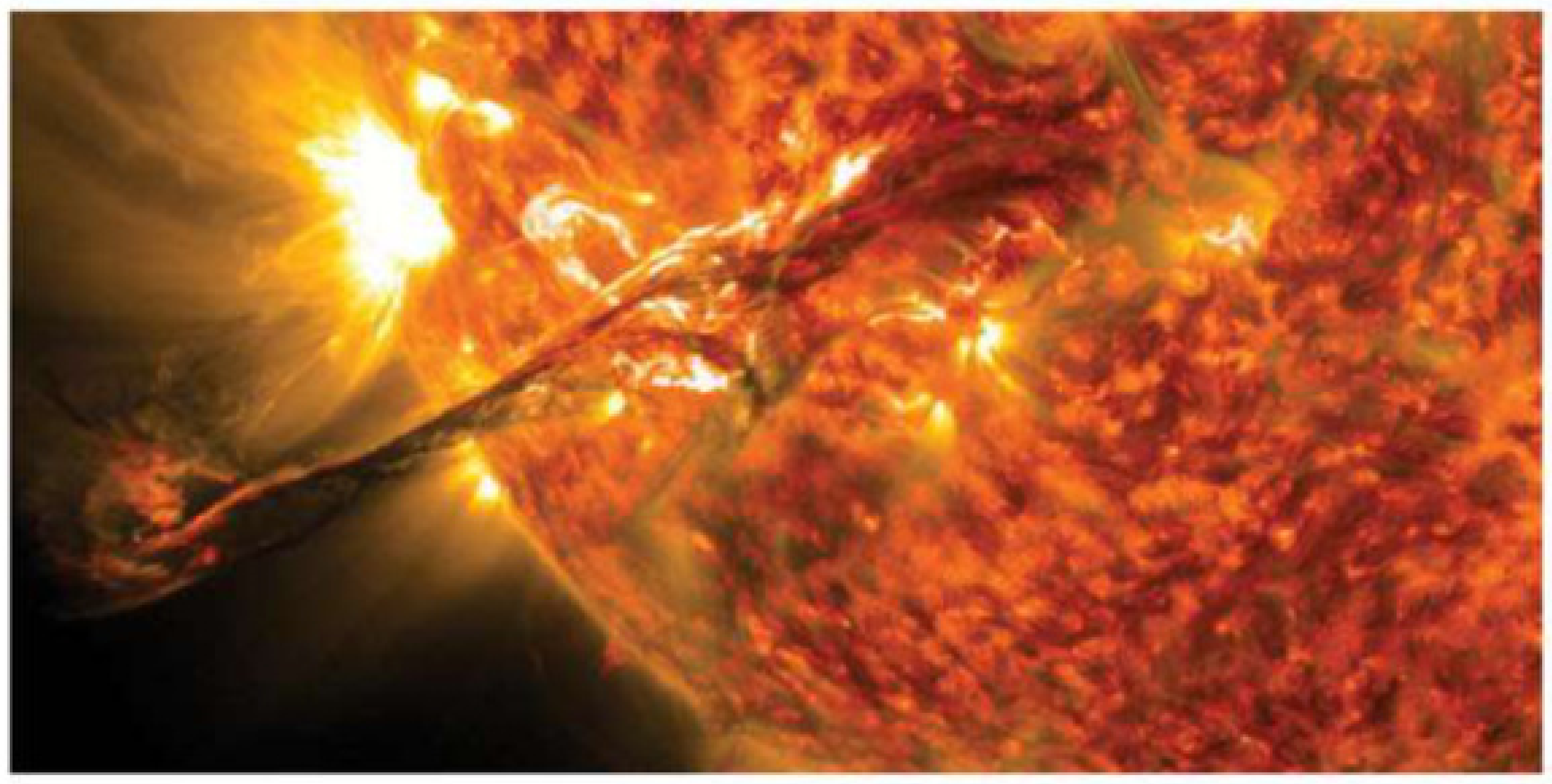
Kepler-88 c alerted astronomers to its presence by perturbing the orbit of its sibling planet, Kepler-88 b

# "We saw the full consequences of a direct hit on our planet"

## Scientist urges governments to prepare for a massive coronal mass ejection event

The most powerful coronal mass ejection (CME) ever recorded in July 2012 last year has prompted renewed investigation and a warning from a University of Colorado at Boulder solar scientist. Professor Daniel Baker, who works at the university's Laboratory for Atmospheric and Space Physics, has been studying the CME and gave a presentation on the subject in December last year: "The message we are trying to convey is that we made direct measurements of the 2012 event and saw the full consequences without going through a direct hit on our planet," said Dr Baker. "My space weather colleagues believe that until we have an event that slams Earth and causes complete mayhem, policy makers are not going to pay attention."

The 2012 CME was a real scare for solar scientists: the ejection travelled at over 11,265,408 kilometres (seven million miles) per hour and was more powerful than the famous Carrington solar storm, the historic CME that blasted the Earth with charged particles in 1859. Earth was in the direct line of fire of the even larger 2012 storm just a few hours after the event, the intensity of which was recorded by NASA's STEREO-A satellite. "We have proposed that the 2012 event be adopted as the best estimate of the worst-case space weather scenario," added Dr Baker. "[This] information can be used to explore what would happen to various technologies on Earth and in orbit, rather than waiting to be clobbered by a direct hit."



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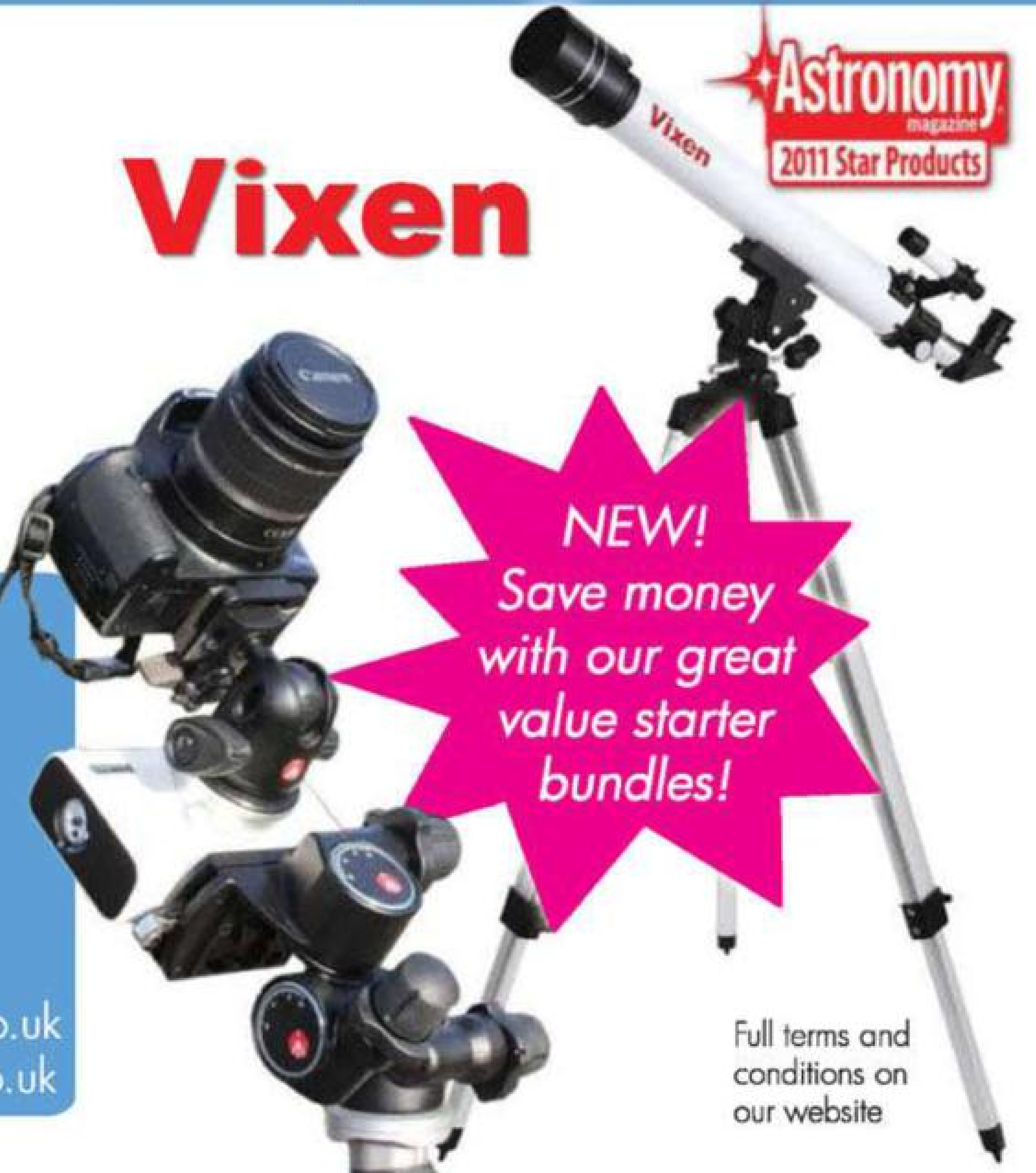

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# Birth of the UNIVERSE

All About Space explores the science and speaks to the scientists who seek the answers to how our universe began

Written by Gemma Lavender

The universe almost seems to have come out of nowhere: a concoction of high temperatures and a thick gloop of exotic particles, which would go into an overdrive of expansion through several phases of varying conditions, to create the universe as we see it today, some 13.8 billion years later. The Big Bang, creator of time and space - or at least that's what our current understanding of how our universe sprang into existence leads us to believe.

But what we have come to learn about the cosmos's somewhat mysterious past wasn't always as tacked down in the days of Georges Lemaître, who would later become dubbed the father of the Big Bang theory. What the Belgian priest, astronomer and professor of physics suspected in 1927, based on his solutions to Albert Einstein's equations, was that the universe must have sparked into life from a single point at the beginning of time before driving headlong into an expansion. "The evolution of the world can be compared to a display of fireworks that has just ended; some few red wisps, ashes and smoke," Lemaître said, on the subject of how we were thrown into existence. "Standing on a cooled cinder, we see the slow fading of the suns, and we try to recall the vanishing brilliance of the origin of the worlds." However, Lemaître wasn't recognised as the genius he was until later; he published his work in an obscure Belgian scientific journal where few scientists saw it. As such Lemaître's chance to go down in history was lost.

Instead, in America one astronomer in particular was gathering the data that would strongly support Lemaître's theory. Edwin Hubble and his assistant Milton Humason were busy at the eyepiece of a 2.5-metre telescope at Mount Wilson Observatory in California, surveying so-called spiral nebulae. These used to be thought of as part of our own Milky Way galaxy, but Hubble showed that they were island universes in their own right, galaxies like our own millions of light years away. He did this by measuring their redshift. This is just like the screaming pitch of a police siren racing past you. As the police car speeds towards you the Doppler effect causes the soundwaves to bunch up, making the pitch go up. As the police car moves away the soundwaves become more stretched and the pitch of the siren falls. In space, objects moving towards us have the wavelength of their light rays compressed into bluer wavelengths, which astronomers term blueshift, while objects moving away have their light stretched into redder wavelengths, hence redshift. Amazingly, Hubble found that almost all the galaxies had redshifts, meaning that they were all moving away from us according to what became known as Hubble's Law. But if the galaxies are all moving apart, could they once upon a time have been much closer together, coming out of a big bang?

In 1931 Lemaître's work was brought to people's attention when Sir Arthur Eddington discovered it, but by then Hubble had already made his discoveries. At first Einstein did not believe it, but later changed his mind when he saw Hubble's evidence. A more vocal critic was astronomer Fred Hoyle at Cambridge University, who came up with the name 'Big Bang' in derision of the idea, and favoured his own Steady State model describing an eternal universe. The Big Bang name stuck, though.

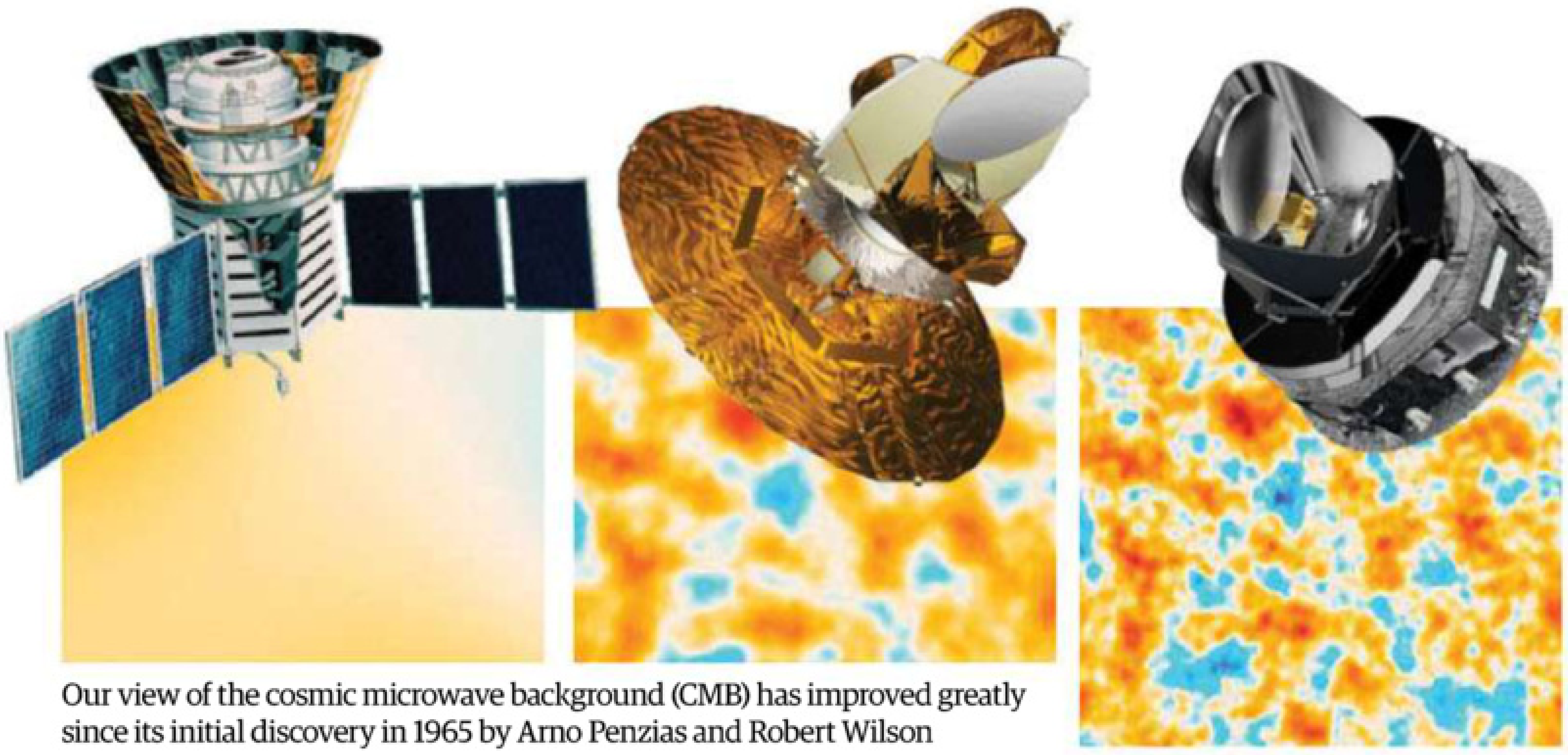
## Meet the experts

**Name: Richard Davis**
Role: Professor
Head of technology at Jodrell Bank. Led his institution's involvement in the Planck mission.

**Name: David Evans**
Role: Professor
Leads the University of Birmingham team on ALICE at CERN's Large Hadron Collider.

**Name: Dan Coe**
Role: Astronomer
Staff astronomer at the STScI, studying galaxy clusters, gravitational lensing and dark matter.

Today, the Big Bang is a widely accepted theory. However, we don't have a photo album of how the universe grew from an infant into the veteran of cosmic evolution that it is today. Astronomers realised that they had to be resourceful, grabbing hold of any evidence that our universe was willing to give up and combining it with mathematical models. Of course, these clues are communicated to us in the cosmos's own way; ranging from the crackling of its background noise - the cosmic microwave background (CMB) - to gravitational waves that ripple between its many galaxies.



Our view of the cosmic microwave background (CMB) has improved greatly since its initial discovery in 1965 by Arno Penzias and Robert Wilson

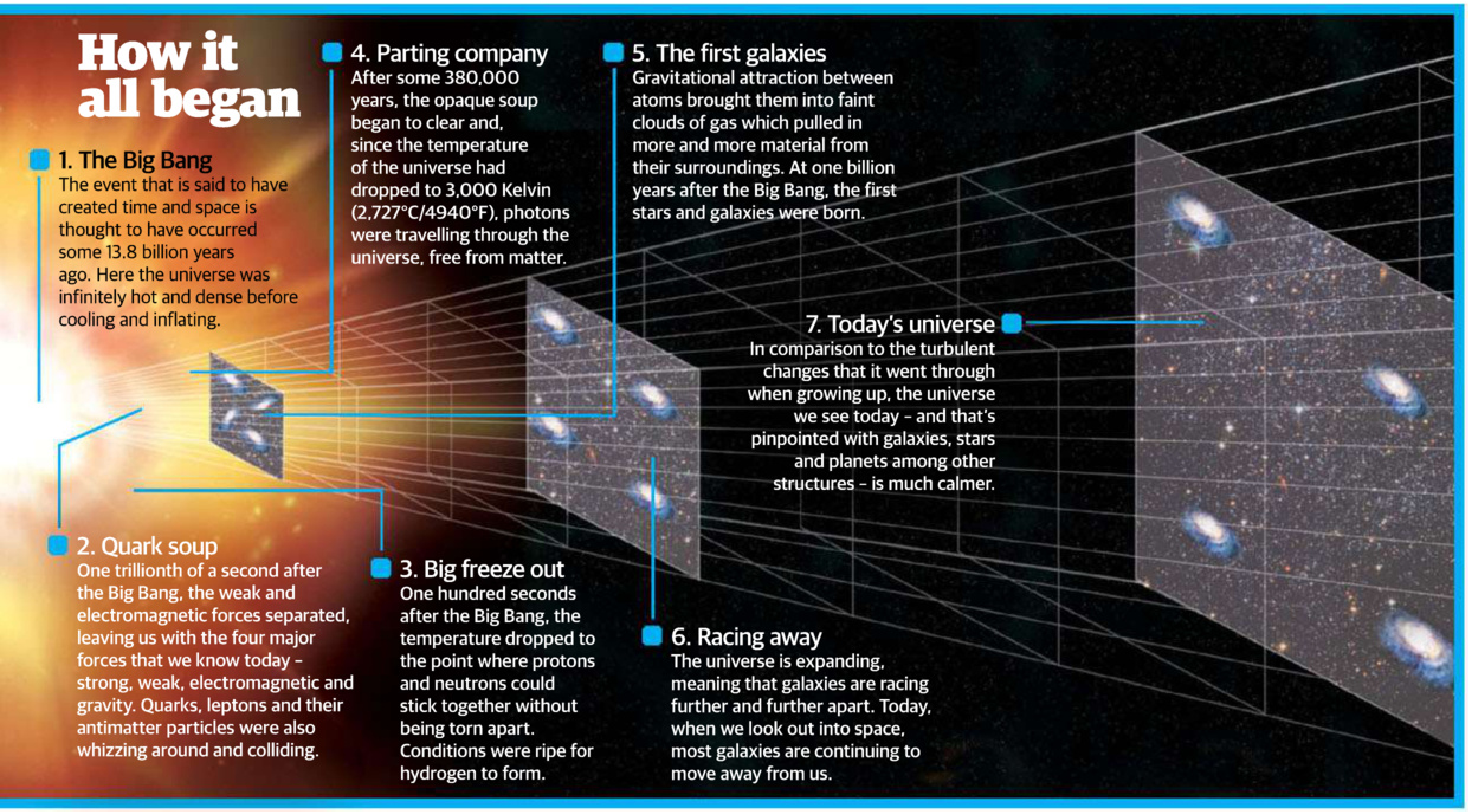
## The cosmic relic

And the universe is certainly telling us things about its past. The CMB was not the stealthiest of beasts when it generated interference on the experiments of Bell Laboratory astronomers Arno Penzias and Robert Wilson in 1965. Their device was called the Holmdel Horn Antenna, a radio telescope that listened in on the universe. Everywhere they pointed it, they detected an unwanted hiss, kind of like the low level of electrical noise that produces 'snow' on a TV screen. Only after they had ruled out every possible alternative did they finally accept that the unexplained signal could be coming from space. What's more, it was coming from all directions. They realised it was the sought-after cosmic microwave background radiation, that scientists suspected might exist. If our universe had a beginning then there was likely to be some kind of residue left over, flavoured in a static of microwave bands; a relic radiation, the cosmic microwave background. And at a temperature of 2.7 degrees above absolute zero (about -270 degrees Celsius or -460 degrees Fahrenheit) it is actually quite cold, making today's universe a chilly place to be as this radiation fills every corner of space. Once upon a time it was quite hot, but has cooled as the universe has expanded.

The CMB was emitted about 380,000 years after the Big Bang, when temperatures in the universe fell to below approximately 3,000 degrees Celsius (5,400 degrees Fahrenheit). At this temperature atomic nuclei were able to soak up all of the free electrons that whizzed around the universe. With the electrons out of the way light and radiation were allowed to freely pass through space without bouncing off electrons, and this is the light that we see now as the cosmic microwave background. So although it doesn't quite show us the moment of the Big Bang, the appearance of the CMB is heavily influenced by what happened in the Big Bang, such as a brief period of inflation that moved parts of the universe apart faster than the speed of light. The picture that the CMB provides is one of the baby universe - it's

> "The picture that the CMB provides is one of the baby universe - it's like we're looking back to when time and space first shuddered into existence"

## How it all began



**1. The Big Bang**
The event that is said to have created time and space is thought to have occurred some 13.8 billion years ago. Here the universe was infinitely hot and dense before cooling and inflating.

**2. Quark soup**
One trillionth of a second after the Big Bang, the weak and electromagnetic forces separated, leaving us with the four major forces that we know today - strong, weak, electromagnetic and gravity. Quarks, leptons and their antimatter particles were also whizzing around and colliding.

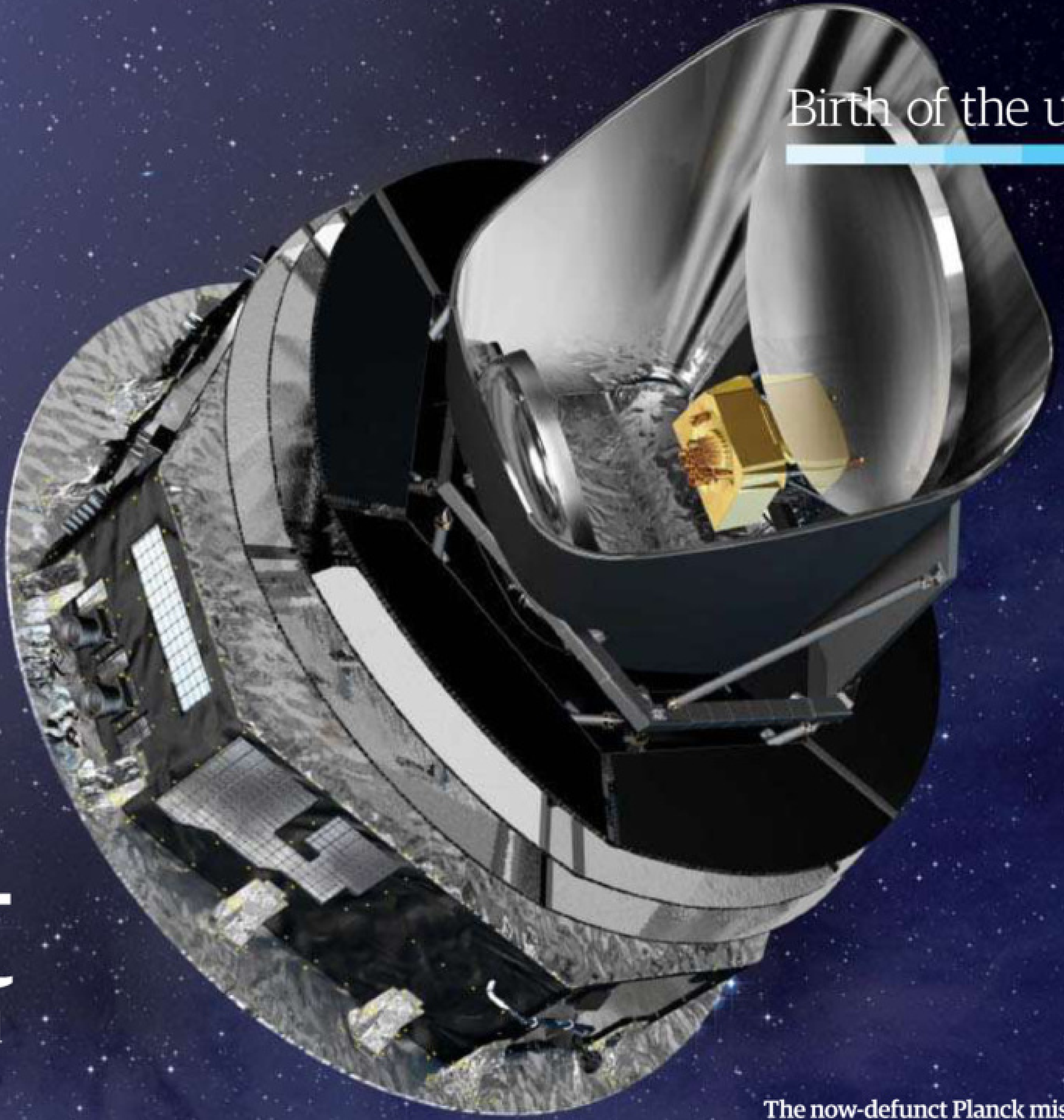
**3. Big freeze out**
One hundred seconds after the Big Bang, the temperature dropped to the point where protons and neutrons could stick together without being torn apart. Conditions were ripe for hydrogen to form.

**4. Parting company**
After some 380,000 years, the opaque soup began to clear and, since the temperature of the universe had dropped to 3,000 Kelvin (2,727°C/4940°F), photons were travelling through the universe, free from matter.

**5. The first galaxies**
Gravitational attraction between atoms brought them into faint clouds of gas which pulled in more and more material from their surroundings. At one billion years after the Big Bang, the first stars and galaxies were born.

**6. Racing away**
The universe is expanding, meaning that galaxies are racing further and further apart. Today, when we look out into space, most galaxies are continuing to move away from us.

**7. Today's universe**
In comparison to the turbulent changes that it went through when growing up, the universe we see today - and that's pinpointed with galaxies, stars and planets among other structures - is much calmer.



The now-defunct Planck mission surpassed expectations in its study of the CMB

# Seeing the start

Astrophysicist Richard Davis explains how we measured the Big Bang

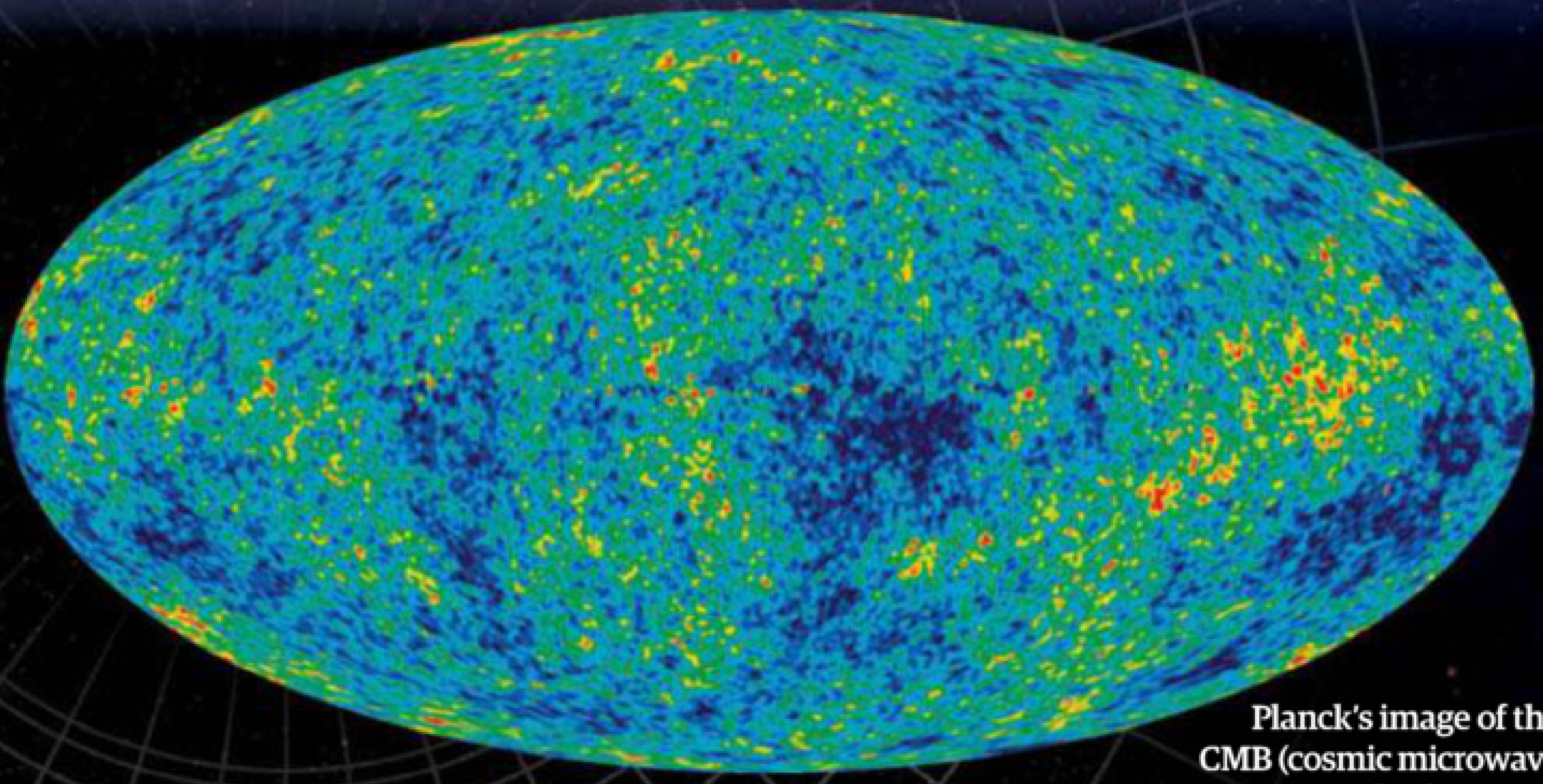
And then there was light. That's pretty much how our universe sprang into existence; as a point that contained everything and continued to expand through to today, building the first stars and galaxies and stretching light years of distance between them. Despite its name, the Big Bang wasn't some kind of explosion that spat out matter, energy, time and space. It is imagined almost like a balloon that continues to stretch, originally holding an incredibly hot and dense primordial soup that cooled and thinned out over the space of millions to billions of years.

As ever, such an event has opened up a whole deluge of questions. And the only way to attempt to look back in time is to lift missions off the ground to seek answers; providing us with the holy grail that is the snapshot of our newborn universe. Several missions have stepped up to the challenge, most notably the recently retired Planck mission – which communicated its final signal of what it knew about the ancient universe in October this year – under the joint efforts of ESA and NASA. Planck built upon and improved observations returned by its complementary mission, NASA's Wilkinson Microwave Anisotropy Probe (WMAP), which, after a good nine years of service, rests in its heliocentric graveyard orbit.

Planck's main aim was to measure the cosmic microwave background (CMB) – the afterglow of the Big Bang, that's encoded with how the universe appeared some 400,000 years after the event. And to get the best measurements possible, the mission had to be kept to freezing temperatures.

"[Planck had] a passive cooling and three refrigerators taking it to -273.05 degrees Celsius [-460 degrees Fahrenheit] which made it the coolest place in the universe," says the University of Manchester's Richard Davis, who led the UK's involvement in one of the instruments on board the craft. "It also had the lowest noise detectors ever made and are lower than anything detected before." An important feature of the CMB is that it is, by no means, smooth – it is a mess of different temperatures and it was from soaking up this relic radiation from its orbit around the Sun that Planck was able to pick out even the most subtle blips in temperature; something that Davis admits the mission did incredibly well. "The fluctuations go down to as low as 2 micro Kelvin," he says. "Planck surpassed its expectations and in some cases even exceeded its goals, so it has been stunning."

Indeed, a couple of the many achievements that the space mission has in its arsenal is an all-sky survey that has provided us with our best view of the oldest light in our universe to now as well as a better measurement of the age of the cosmos, dated at 13.8 billion years old – 100 million years more than previously thought. And even though the mission has since been deactivated, Davis assures us that Planck could still wield the key to understanding more about our infant cosmos. "We will go on analysing the data for at least the next ten years so there is much to come," he says. "We will release the data in the next few years."

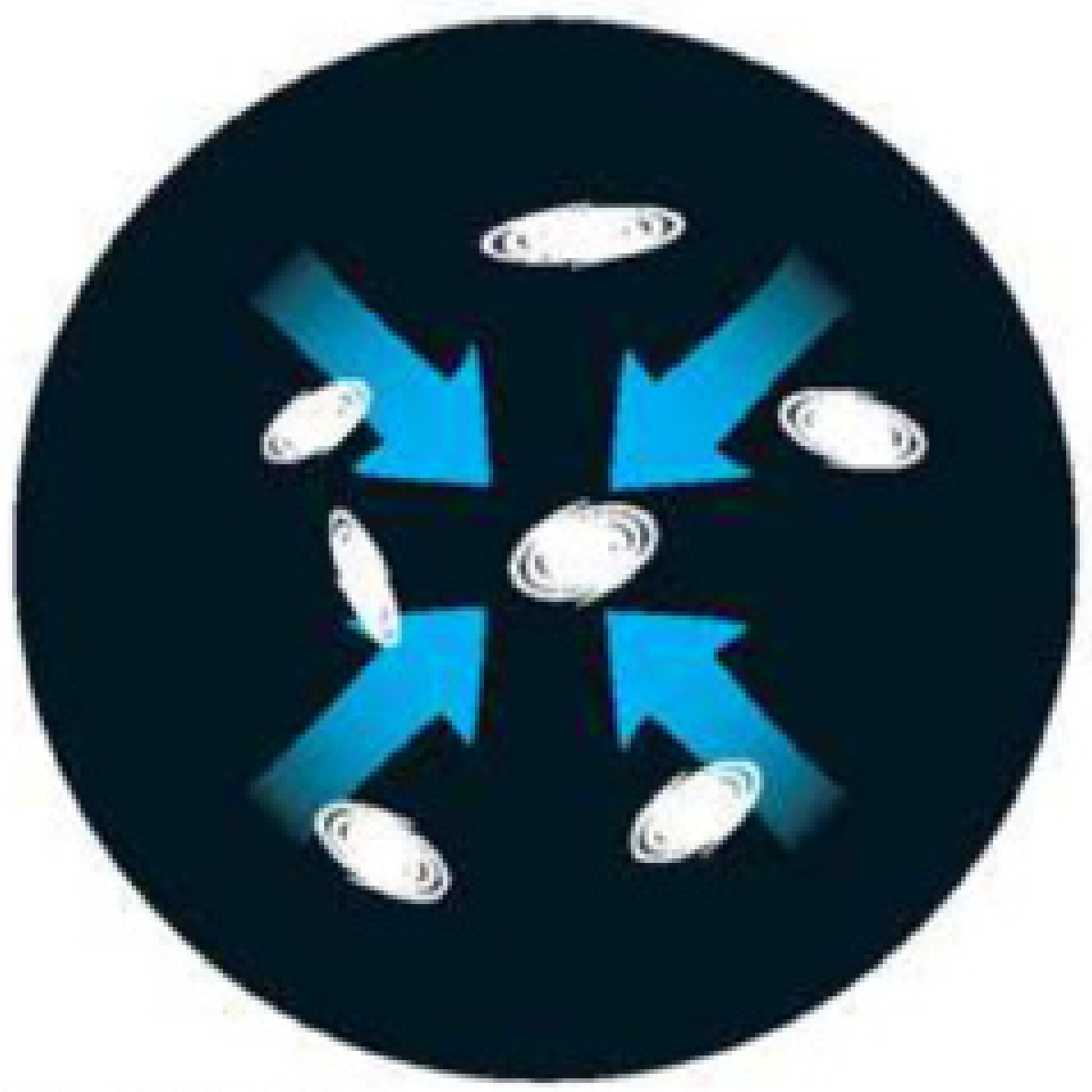


Planck's image of the CMB (cosmic microwave background)

> "Planck surpassed its expectations and in some cases even exceeded its goals, so it has been stunning" **Richard Davis**

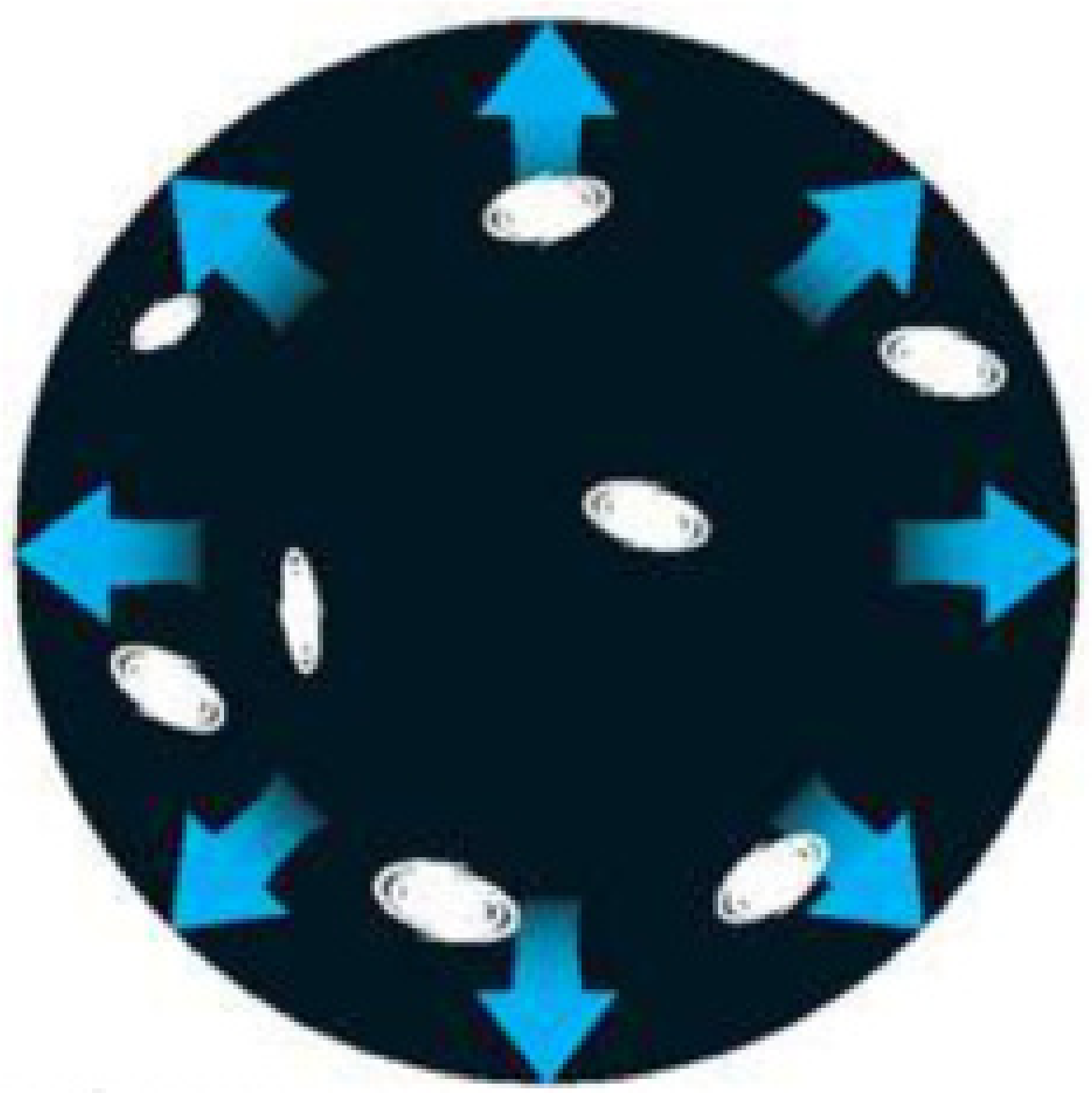
## How it will end

There are thought to be three possible ways the universe will end. One is the Big Crunch, where gravity takes over and compresses it to one point. Another is the Big Rip, where the expansion of the universe gets faster until galaxies, stars, planets and space itself is torn apart. Then somewhere between these extremes is the likely scenario where the universe's expansion is not great enough for a Big Rip and gravity is not strong enough for a Big Crunch. Instead the universe will continue to expand, growing cold and lifeless - the Big Freeze.



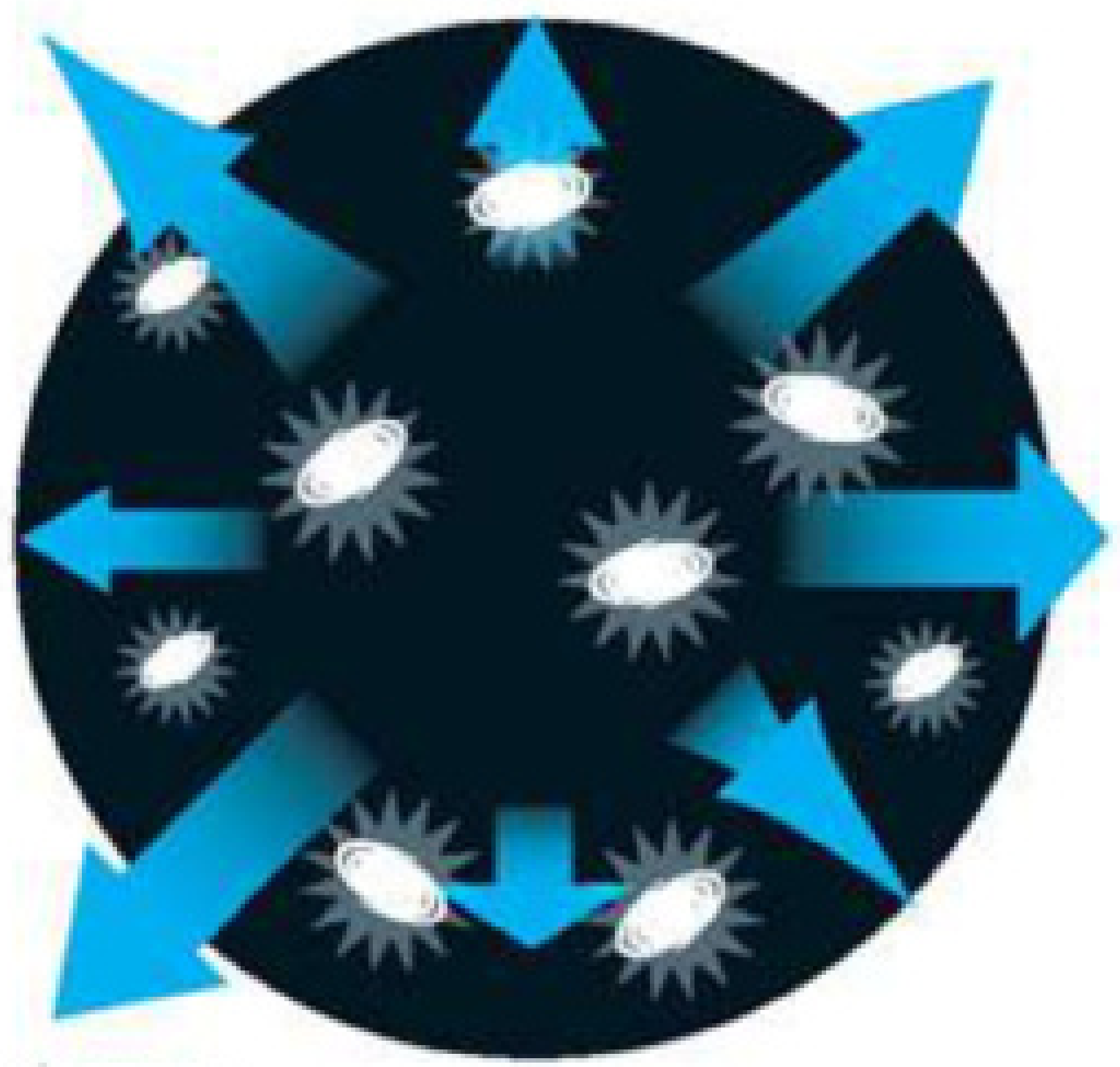
### Closed universe

The density of the universe is more than five atoms of hydrogen per cubic metre. There's no repulsive effect of dark energy and gravity eventually halts the universe's expansion. With contraction, all the matter in the universe collapses to a point - the Big Crunch.



### Open universe

If space is open and curved, the universe will continue to expand forever. Dark energy will help to drive the expansion. The result? Heat death, the Big Freeze or the Big Rip is imminent. Here the universe's density is less than the critical density.



### Flat universe

With no dark energy, a flat universe will expand forever at a decelerating rate. With dark energy the expansion initially slows thanks to gravity, then speeds up. The universe's ultimate fate is the same as if it were open. Density and critical density are equal.

The eLISA spacecraft will attempt to test the complex art of gravitational wave detection. Gravitational waves create the ripples in space-time thought to be additional evidence for the Big Bang theory

"Planck imaged the cosmic microwave background in unprecedented detail"

like we're looking back to when time and space first shuddered into existence.

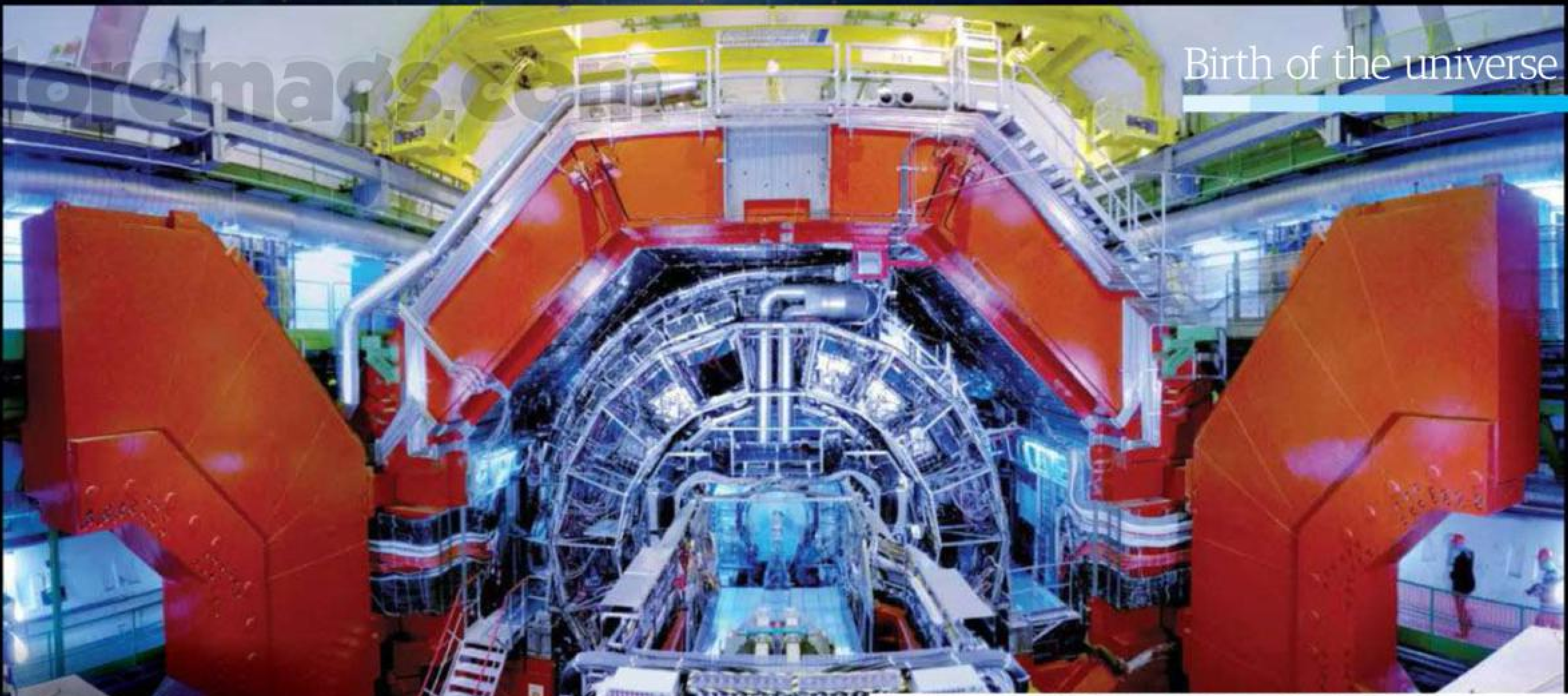
## Mapping the sky

Penzias and Wilson were awarded the Nobel Prize for their discovery, but there was still much to learn about the microwave background - we wanted a map. The first mission to attempt this was the NASA-owned Cosmic Background Explorer (COBE) probe, which began snapping pictures of the CMB as soon as it was launched in 1989. Offering four years of service, COBE announced the very first map of hot and cold spots within the CMB brought about by the early universe's gravitational field that would later form the seeds of gigantic clusters of galaxies that stretch for hundreds of millions of light years across the universe. COBE's lead scientist, George Smoot, also won the Nobel Prize, but hot on the heels of COBE came the Wilkinson Microwave Anisotropy Probe (WMAP). It boasted an improved resolution and got to work mapping the entire sky, logging the differences in temperature of the microwave radiation down to 25 millionths of a degree. What WMAP also uncovered told astronomers about the shape of the universe; they figured that since the boldest and brightest bursts in the map were a mere one degree across, then we must be living in a flat universe. By 2010, WMAP had sniffed out its last microwave, producing over nine years of information. WMAP had laid down some important foundations, making the mission a huge breakthrough. Meanwhile, as WMAP was put into retirement, a new space observatory was waiting in the wings, ready and willing to build on our knowledge of the early universe thus far - ESA's Planck. Operating in a range of microwave and infrared frequencies, the spacecraft promised an even higher level of accuracy, putting its instruments into overdrive in an attempt to lock down any answers given away by the deepest recesses of the universe. And Planck gave as good as it got from the universe, imaging the CMB in unprecedented detail. It might have ended its mission in October, but we are now the proud owners of a more accurate picture of an almost perfect universe as well as a more prominent point in time when the event began. The truth of the matter is that this microwave background isn't the only feature of the universe that's telling us how it began - there's more tantalising evidence and we're making sure that we're taking advantage of it.

And these extra telltale signs are the ripples in space-time - gravitational waves. These elusive oscillations represent one of the missing pieces of Einstein's theory of relativity. Gravitational waves can be created by all kinds of massive objects, but some were also believed to have formed in the Big Bang and could still be rippling through the universe today. The problem is that it's not easy to directly detect them but their elusive behaviour means that the universe also has difficulty influencing them under its will. This is good news for us as they are the only known form of information that's able to reach us undistorted from the time of the Big Bang. The trick is catching them as you need incredibly sensitive detectors. Not put off by their shyness, scientists have been intent on pinning these waves down. Unlike the common electromagnetic radiation that we're used to, gravitational waves, which are the result of massive events such as the merging of supermassive black holes, like to work their way through all types of matter - whether it be gas or dust.

Previous attempts to grab gravitational waves by the tail, which includes the likes of a large-scale experiment called the Laser Interferometer Gravitational-Wave Observatory (LIGO), haven't gone unnoticed but have sadly been fruitless. We need something better and while 'advanced LIGO' is in the works for next year ESA has been thinking outside our Earth's atmosphere and straight into the thick of space. The plan is to build a mission that has the ability to deal with such a slippery character. Scientists think they might have that pegged with the help of a planned mission, the evolved Laser Interferometer Space Antenna (eLISA) - a large-scale space mission that will not only detect this elusive phenomenon, but will also be able to survey the entire universe directly with these waves, giving us more information on the formation of galaxies, how stars grow and the early universe. And that's not all, planned for launch in the future, the people behind the craft proudly proclaim that it will also be able to tell us more about the structure and nature of space-time. There will also be the opportunity for uncovering more about black holes as well as other unknown objects. Before it can begin to achieve its goals, an advance scout named LISA Pathfinder will launch in 2015, paving the way for eLISA to test the complex art of gravitational wave detection.

As we understand it, from the reams of data brought about by the teamwork between missions



A Large Ion Collider Experiment (ALICE) is one of seven detector experiments at the Large Hadron Collider at CERN. Colliding lead nuclei, the resulting smash-up is thought to be enough to produce a quark soup

David Evans, who is heavily involved with the ALICE experiment at CERN, examines the inside of its chamber

# Re-creating the Big Bang

Professor of high energy physics David Evans is making baby universes

Tucked away in the highly populated city of Geneva in Switzerland, the particle-smashing Large Hadron Collider (LHC) - built by the European Organisation for Nuclear Research, which is more commonly known as CERN - has been hard at work accelerating particles to breakneck speeds close to the speed of light. The aim? To attempt to re-create what the early universe might have been like just a few minutes after it was born. The particle accelerator, which houses two detectors dedicated to pinpointing the moments during our universe's growth (LHCb and ALICE), works as a Big Bang-making machine. The differences are that this 'explosion' is on a much smaller scale and scientists have a bit more control over it.

For ALICE, the aim of the game is to smash particles of lead into each other to create a plasma that existed some ten millionths of a second after the Big Bang. "Lead atoms have all of their 82 electrons stripped off and the positively charged nuclei are accelerated to over 99.9999 per cent the speed of light in the LHC," says the University of Birmingham's David Evans, who leads the team working on the ALICE experiment. "The lead nuclei then smash together inside the giant ALICE detector and, for a brief instant, create a super hot and dense sub-atomic fireball."

What these results show is that the tiny fireballs - which are a lot smaller than a single atom - that Evans speaks of, reach temperatures of a scorching six billion degrees Celsius (10.8 billion degrees Fahrenheit). That's over 300,000 times the temperature of our Sun and, what's more, the density that results is 50 times that of a neutron star. "Such extreme temperatures and densities would have last existed just about a millionth of a second after the Big Bang and, under these conditions, protons and neutrons (which make up the nuclei of atoms) 'melt' into a soup of fundamental particles called quarks and gluons," adds Evans. "This primordial soup is called a quark-gluon plasma."

Evans believes that the plasma they produce in ALICE is fairly representative of the early gloop of the early universe. "However, the fireball we create is much smaller than the one in the early universe and, hence, will cool much quicker," he says, before adding that the results brought about by the detector are indicative of breakthroughs in our understanding of the early cosmos. "Although it's still early days," Evans tells us, "our results show that the quark-gluon plasma seems to behave like the most perfect liquid ever produced. So it seems the universe was born of a perfect liquid."

Another surprise was just how strong the forces are in this plasma where high-energy particles, usually found to barge their way through metres of thick detector material, find themselves absorbed in incredibly small distances not much bigger than the nucleus of an atom.

At the moment, the LHC has been shutdown for several upgrades but, as soon as it's up and running again in early 2015, Evans and his team will be putting it to even more good use. "We will be able to collide lead nuclei at double the energy, creating even hotter and denser fireballs," he explains. "We are really just at the beginning of an exciting endeavour to discover the properties of the quark-gluon plasma, I am expecting to find many surprises along the way."

Meanwhile, the team behind the LHC experiment will get back to trying to work out why there were unequal amounts of antimatter and matter. Of course, the Large Hadron Collider has also done us proud by unearthing the Higgs Boson - the particle that is responsible for all of the mass in the universe.

> "The quark-gluon plasma seems to behave like the most perfect liquid ever produced" **David Evans**

and theories, we think we've put together a pretty robust photo album - or timeline - from the universe's birth all the way through to its 13.8 billion-year-old self. Shortly after its sudden appearance, there was nothing except for a plasma soup. The universe was incredibly hot with particles of both matter and antimatter - the opposite of matter - rushing apart in all kinds of directions. Then it began to cool, producing equal amounts of matter and antimatter, which swiftly annihilated each other. Lucky for us, for some reason that nobody yet understands, there was extra matter leftover and, as the universe began to peter out, cooling further, particles - the building blocks of matter - began to take shape. The first stars formed around 400 million years after the Big Bang, followed by the first galaxies - the oldest galaxies we have seen so far are a whopping 13.2 billion years old.

As much as we are sure the Big Bang happened, the nature of the universe still raises existential questions. Where did the universe come from? Why did it appear in the first place? Why was there more matter than antimatter in the early universe? Why is dark energy causing the expansion of the universe to accelerate? What we do know is that the Big Bang was not an 'explosion' into anything, it happened everywhere, which is why everywhere is filled with the CMB. And we also know that the ultimate destiny of the universe depends on what wins the great cosmic battle over the fate of the cosmos: will gravity tug the universe back, or will dark energy keep it expanding forever? ■

## Missing pieces

It might be the king of theories when it comes to explaining the birth of the universe, but the Big Bang theory still hits a few snags.

### 1. Disappearing antimatter

In the beginning, there were equal amounts of matter and antimatter - two materials that, when they come together, annihilate each other. Why, then, does our universe now contain mostly matter?

### 2. The horizon problem

Are the widely separated regions of the sky too far apart to communicate with one another? If they're unable to communicate, scientists are unsure how they know to have the same temperature.

### 3. The flatness problem

Evidence suggests that the present universe is pretty much flat. Experts think that its current form is a very unlikely result of the universe's evolution from the Big Bang.

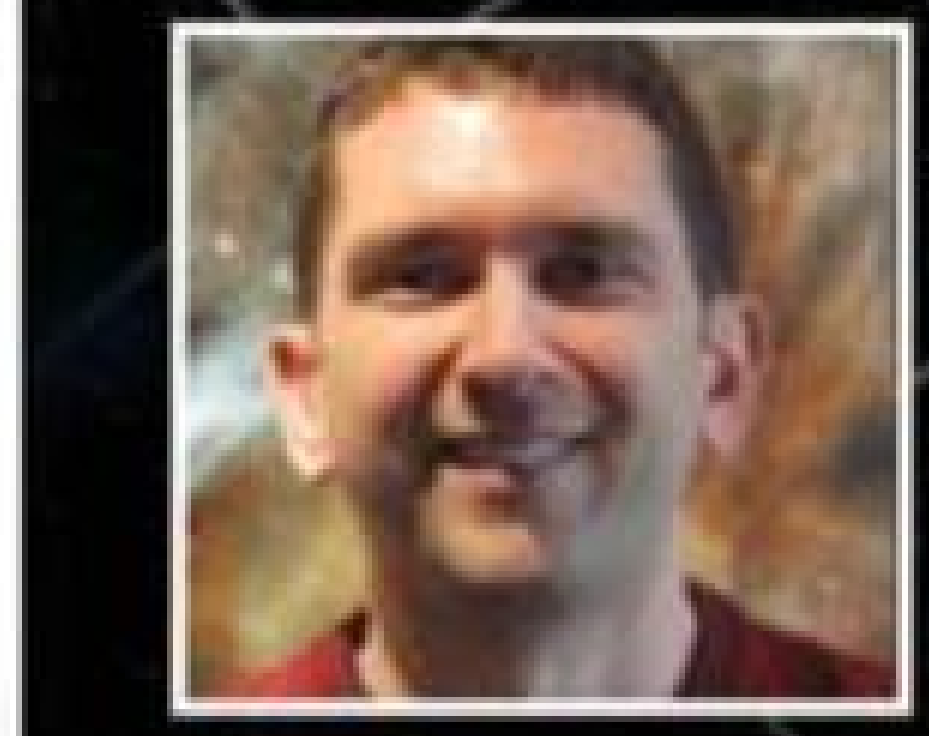
### 4. Galaxy formation

Random bumps in the expanding universe may not be enough to form galaxies. In a rapidly expanding universe, gravitational attraction loses the fight and is too slow for these structures to form.

### 5. The monopole problem

The Big Bang predicts that a large number of 'magnetic monopoles' should have been made in the early universe. But they've never been seen, so, if they exist at all, they're much rarer than predicted!

# Observing the aftermath



Astronomer David Coe is looking at the Big Bang's deep space consequences

Around 13.8 billion years later, here we are. As the stars, galaxies, planetary systems and other bodies are silently suspended in an endless void of blackness, it is difficult to believe that there was a time in the universe's life that conditions were chaotic and ever-changing. But there is evidence everywhere and in all directions; the Hubble Deep Field - snapped by the long-serving Hubble Space Telescope - made sure of that.

"The Hubble Deep Field revealed distant galaxies which appear very different from nearby galaxies," explains Dan Coe, an astronomer at the Space Telescope Science Institute in Maryland, USA. "They are generally smaller, more clumpy and less orderly than nearby galaxies and yet to form spiral patterns or settle into elliptical balls."

Constructed from a series of observations over a period of ten days, this tiny snapshot - which is equivalent in size to a 65-millimetre tennis ball held at a distance of around 100 metres away - holds 3,000 objects, most of which are galaxies. Several of these structures are among the youngest and most distant known - providing a pathway that allows us to look back to when the universe was young. "Distant galaxies appear redder," says Coe. "This 'redshift' is due to the expansion of the universe. As the universe expanded over billions of years, it stretched light along with it into longer, redder wavelengths. Ultraviolet starlight emitted billions of years ago from distant galaxies has been stretched along its journey to our telescopes to red or even infrared wavelengths."

The advent of a new infrared camera on board Hubble saw astronomers take the opportunity to look into the universe's past and to reveal ever more distant galaxies with greater redshifts. "Even if our eyes were as large as Hubble's, these galaxies would remain invisible to us," says Coe. "We believe the most distant galaxy detected in the Ultra Deep Field dates back to 500 million years after the Big Bang, over 13 billion years ago."

But Coe and his colleagues are looking further still. "The Hubble Ultra Deep Field was about twice as big as the original," he says. "We are now embarking on a large new Hubble programme to observe 12 more Ultra Deep Fields in different parts of the sky." The programme Coe is referring to is a new venture called Frontier Fields and will tell us how similar other patches of sky look to the Ultra Deep Field; that way we can confirm whether the cosmos is expanding in all directions. "It will also use cosmic zoom lenses known as gravitational lenses to magnify the distant universe and observe even more deeply." The Spitzer and Chandra space telescopes will also take images of the Frontier Fields, in infrared and X-ray.

Coe reminds us that terrestrial telescopes that have surveyed wide areas of the night sky have found that the universe looks similar in all directions. "Over billions of years, gravity has woven a 'cosmic web' of dark matter that funnels gas in to form stars and galaxies and draws galaxies together to form large clusters of galaxies," he explains. "The original Ultra Deep Field may have landed on a dense cosmic knot or a cosmic void. That's why we need more Ultra Deep Fields, to sample more of the distant cosmos."

> "The Hubble Ultra Deep Field was about twice as big as the original"
> **Dan Coe**

Coe and his colleague Jennifer Lotz, an assistant astronomer also at the Space Telescope Science Institute, who leads the Frontier Fields programme

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# Nautilus-X

## The artificial gravity spacecraft that could take humans to the Moon and beyond

When it comes to manned missions into deep space there are no shortage of proposals on the drawing board. People have dreamed up spacecraft with various fantastical elements, from futuristic propulsion engines to somewhat ambitious aesthetic designs, but one proposal that warrants a serious glance is Nautilus-X. It's a spacecraft that builds largely on existing technology to make human exploration of the Solar System a realistic possibility, and at a reasonable price, too.

Drawn up by NASA engineers Mark Holderman and Edward Henderson, this deep space vehicle might not be as exciting to look at as some of the other futuristic proposals being touted but it's certainly one of the most promising. The full name of the vehicle is the Nautilus-X, which stands for Non-Atmospheric Universal Transport Intended for Lengthy United States Exploration, while this type of spacecraft is known as a Multi-Mission Space Exploration Vehicle (MMSEV).

Nautilus-X would be capable of supporting a crew of six for missions lasting from one month to two years. Although it might look like a mini space station, the whole thing is designed to be able to travel throughout the Solar System, be it near the Moon or Mars. Although not capable of descending to the surface of another world itself, it has docking ports to which landing craft can be attached.

The intention of the vehicle is that, once built, it could remain in space for many years with several different crews utilising it. For example, one crew could travel to Nautilus-X in an Orion spacecraft and then take the entire spacecraft to Mars for a mission lasting up to a year. They would then return in Nautilus-X at the conclusion of the mission and leave the spacecraft near Earth orbit, ready and waiting for another crew, while they travel back to the surface of Earth in their Orion capsule.

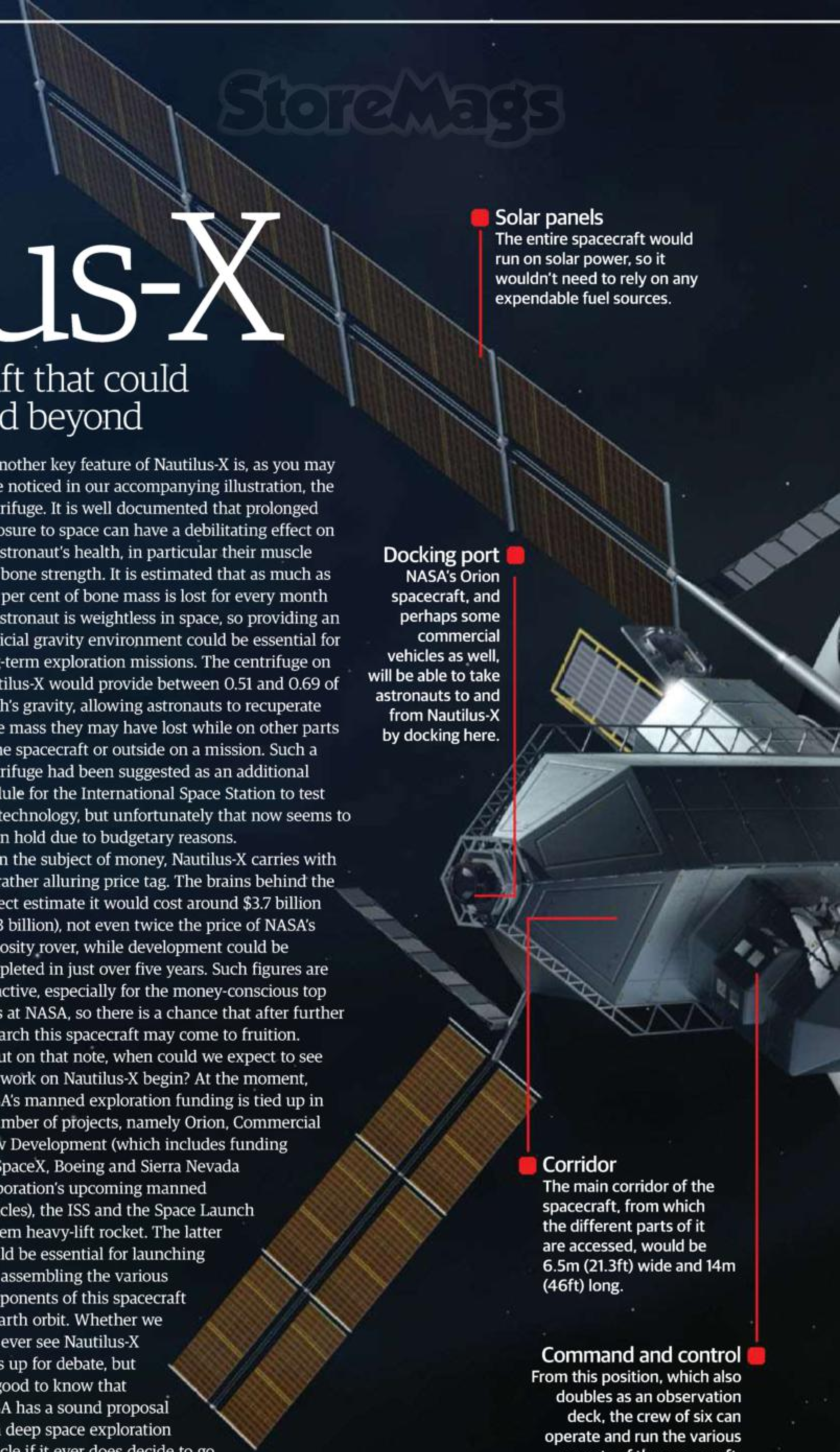
Such an implementation would allow multiple rotating crews to make use of the spacecraft on a variety of missions. Solar panels would make the station almost entirely self-sustainable, while on-board farms could provide astronauts with food. At the outset of a mission, though, it's likely astronauts would need to bring some supplies with them, perhaps on a separate spacecraft such as SpaceX's Dragon.

Another key feature of Nautilus-X is, as you may have noticed in our accompanying illustration, the centrifuge. It is well documented that prolonged exposure to space can have a debilitating effect on an astronaut's health, in particular their muscle and bone strength. It is estimated that as much as two per cent of bone mass is lost for every month an astronaut is weightless in space, so providing an artificial gravity environment could be essential for long-term exploration missions. The centrifuge on Nautilus-X would provide between 0.51 and 0.69 of Earth's gravity, allowing astronauts to recuperate bone mass they may have lost while on other parts of the spacecraft or outside on a mission. Such a centrifuge had been suggested as an additional module for the International Space Station to test the technology, but unfortunately that now seems to be on hold due to budgetary reasons.

On the subject of money, Nautilus-X carries with it a rather alluring price tag. The brains behind the project estimate it would cost around $3.7 billion (£2.3 billion), not even twice the price of NASA's Curiosity rover, while development could be completed in just over five years. Such figures are attractive, especially for the money-conscious top dogs at NASA, so there is a chance that after further research this spacecraft may come to fruition.

But on that note, when could we expect to see any work on Nautilus-X begin? At the moment, NASA's manned exploration funding is tied up in a number of projects, namely Orion, Commercial Crew Development (which includes funding for SpaceX, Boeing and Sierra Nevada Corporation's upcoming manned vehicles), the ISS and the Space Launch System heavy-lift rocket. The latter would be essential for launching and assembling the various components of this spacecraft in Earth orbit. Whether we will ever see Nautilus-X fly is up for debate, but it's good to know that NASA has a sound proposal for a deep space exploration vehicle if it ever does decide to go down that route.

> "Nautilus-X would be capable of supporting a crew of six for missions lasting from one month to two years"

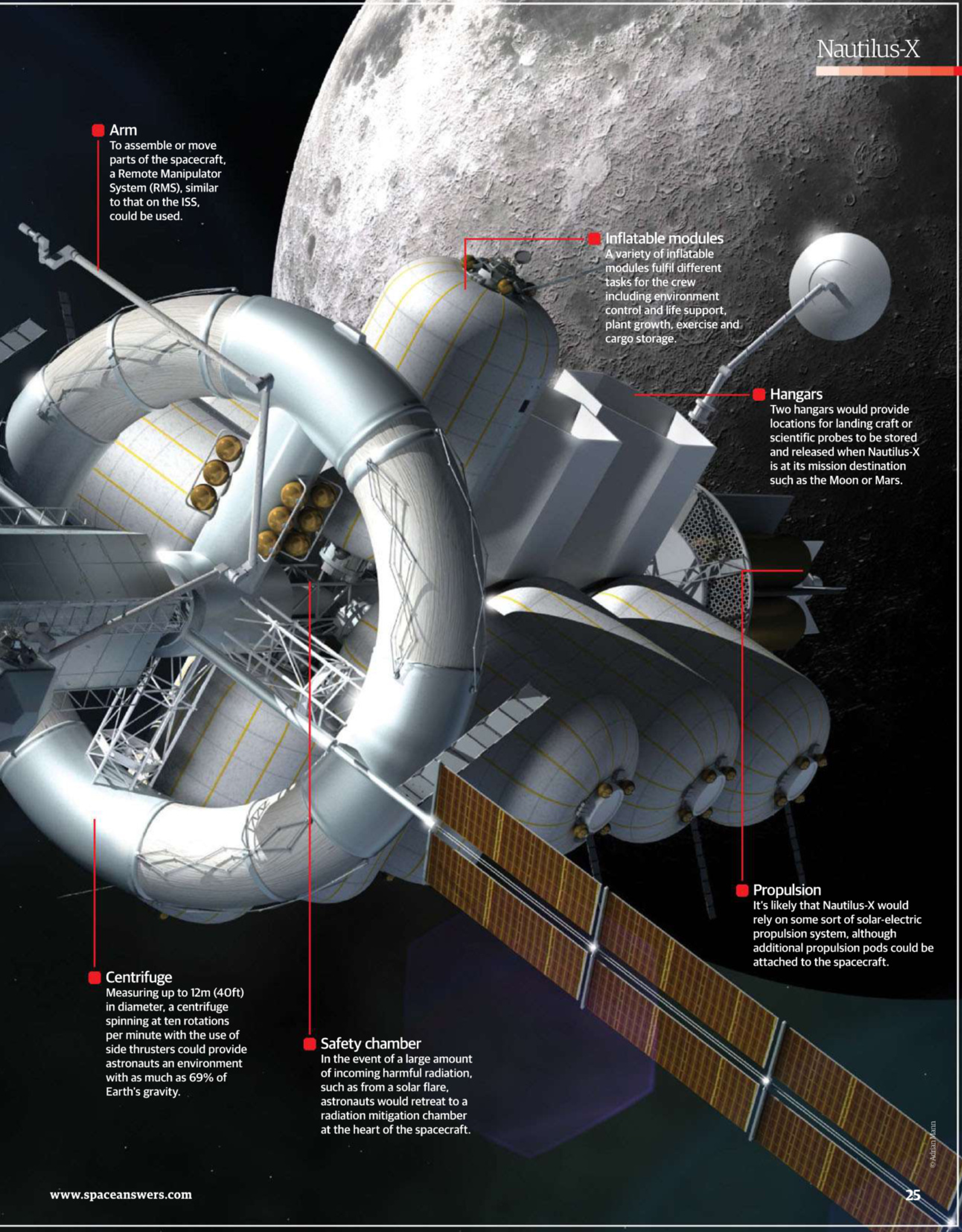


**Solar panels**
The entire spacecraft would run on solar power, so it wouldn't need to rely on any expendable fuel sources.

**Docking port**
NASA's Orion spacecraft, and perhaps some commercial vehicles as well, will be able to take astronauts to and from Nautilus-X by docking here.

**Corridor**
The main corridor of the spacecraft, from which the different parts of it are accessed, would be 6.5m (21.3ft) wide and 14m (46ft) long.

**Command and control**
From this position, which also doubles as an observation deck, the crew of six can operate and run the various aspects of the spacecraft.



**Arm**
To assemble or move parts of the spacecraft, a Remote Manipulator System (RMS), similar to that on the ISS, could be used.

**Inflatable modules**
A variety of inflatable modules fulfil different tasks for the crew including environment control and life support, plant growth, exercise and cargo storage.

**Hangars**
Two hangars would provide locations for landing craft or scientific probes to be stored and released when Nautilus-X is at its mission destination such as the Moon or Mars.

**Propulsion**
It's likely that Nautilus-X would rely on some sort of solar-electric propulsion system, although additional propulsion pods could be attached to the spacecraft.

**Centrifuge**
Measuring up to 12m (40ft) in diameter, a centrifuge spinning at ten rotations per minute with the use of side thrusters could provide astronauts an environment with as much as 69% of Earth's gravity.

**Safety chamber**
In the event of a large amount of incoming harmful radiation, such as from a solar flare, astronauts would retreat to a radiation mitigation chamber at the heart of the spacecraft.

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# A-Z of the MILKY WAY

**All About Space** takes you on an alphabetical journey right through all 100,000 light years of the galaxy Earth calls home – the Milky Way

**Written by Gemma Lavender**

It's one of many galaxies littering the vast expanse of the universe but the Milky Way galaxy has something that we hold dear to us; among its 400 billion stars lies our home, making this gigantic structure – whose stars are tightly knitted together by gravity – the only place that we know for sure life exists. While it might not be the largest galactic structure we know of, the Milky Way is certainly no dwarf – stretching some 100,000 light years across with a disc about 1,000 light years thick, our galaxy is a giant. Packed with stars, planets, dust and dark matter, the Milky Way is given its heft, tipping the scales at around 1.5 trillion times the Sun. Nestled at the heart of our galaxy, we meet Sagittarius A* – the 4 million solar mass supermassive black hole that burps out intense radio emissions after feeding on gas and dust that fall into its clutches. On the outskirts of the Milky Way we encounter its many satellite galaxies, tiny structures that loyally stay by its side.

The subject of debate between scientists of today and for many years before our time, we might live inside the Milky Way, orbiting its centre at 220 kilometres (137 miles) per second, but there are many secrets that our galaxy keeps under lock and key. But given that we have only completed around 1/1,250 of a revolution around its gigantic centre since humans first appeared on Earth, we are coming on leaps and bounds when it comes to exploring our galaxy. So get ready for a journey back in time to the work of great astronomers, hitch a ride with the missions that solved some of the Milky Way's biggest mysteries, move closer to some of the different types of stars and peer into the deepest regions of space at our Milky Way's galactic neighbours as **All About Space** takes you on an alphabetic tour of this great structure. ●

**Norma and Outer Arm**
Extending from the centre of the Milky Way galaxy, the Norma Arm is a somewhat minor spiral arm with a radius of up to 50,555 light years across. It is split into two with the second part of it – the Outer Arm – stretching out the furthest.

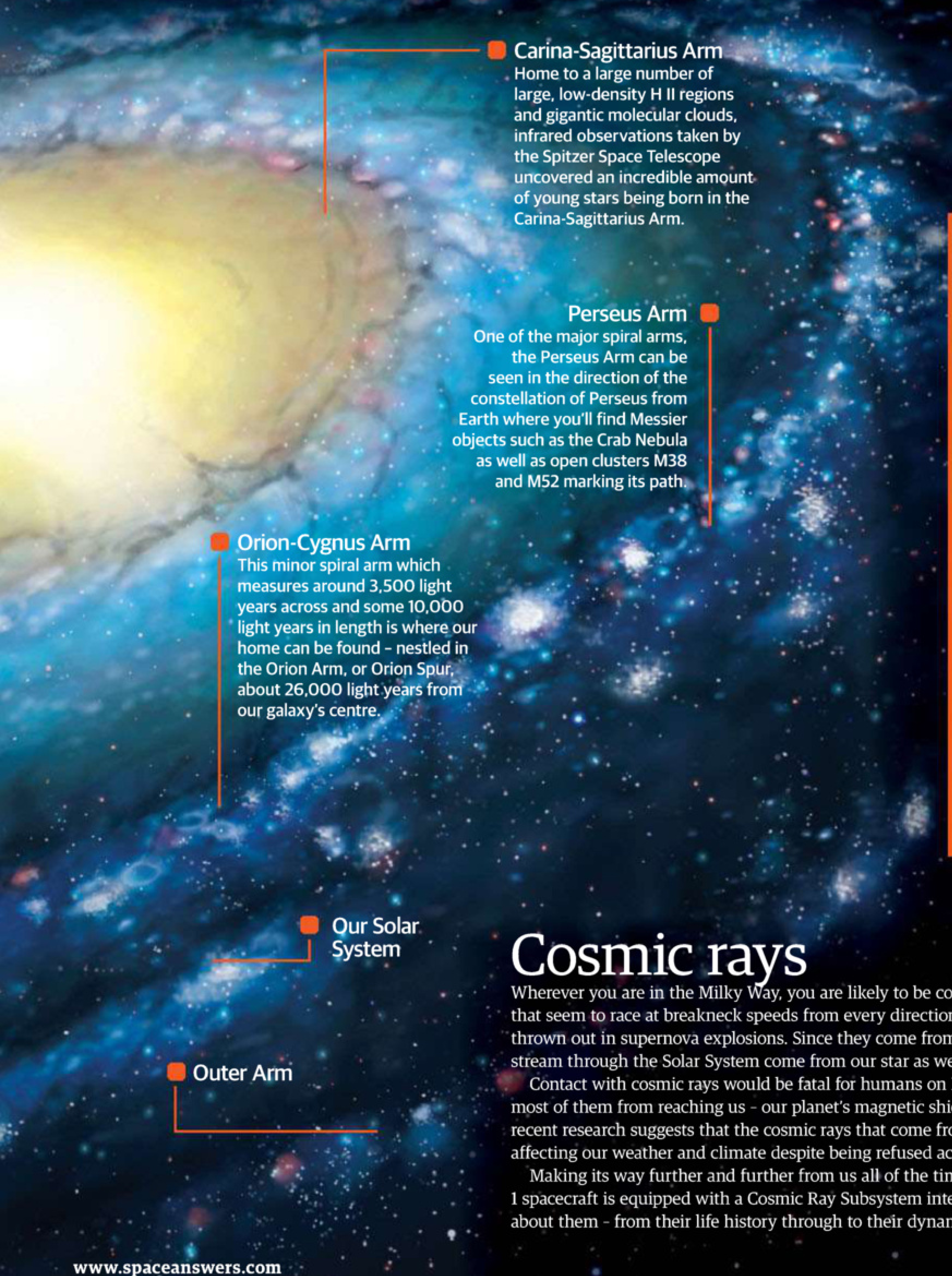
**Scutum-Centaurus Arm**
A curving streamer of diffuse stars, gas and dust makes up the Scutum-Centaurus Arm. Beginning near the galaxy's core as the Scutum Arm, it blends into the Centaurus Arm hitting an extremely intense region rich in the birth of young stars.

# Arms

While we have never travelled outside of the Milky Way ourselves or grabbed a bird's-eye view with the help of the latest spacecraft, what astronomers do know is that our galaxy sports majestic arms. However, just how many is something that they're not fully certain of.

So, over time, experts have put together a picture of how the Milky Way should look according to our observations and piecing together of scientific models from Earth. And what they have come up with is a structure of outstanding beauty, featuring four major arms of billions of hot, glowing stars that wrap around an incredibly bright centre before reaching out into the cosmos. Containing more gas and dust, the galaxy's arms are the birthplace of young stars as conditions get so hot and cramped that the next generation are born. We know the Milky Way's arms, moving out from the centre, as the Perseus, Scutum-Centaurus, Carina-Sagittarius and the Norma and Outer Arms.

Up to this point, you might imagine our galaxy as a perfect spiral - like what you'd expect from the intricate pattern of a seashell, but this isn't quite true. The Milky Way's arms branch, merge and twist unexpectedly. As a result, features such as the Orion-Cygnus Arm are evident; smaller arms or spurs some 3,500 light years across and 10,000 light years in length that seem to push their way into the galaxy's other arms. It is here that our Sun and Solar System rest - 26,000 light years from the galaxy's centre.



**Carina-Sagittarius Arm**
Home to a large number of large, low-density H II regions and gigantic molecular clouds, infrared observations taken by the Spitzer Space Telescope uncovered an incredible amount of young stars being born in the Carina-Sagittarius Arm.

**Perseus Arm**
One of the major spiral arms, the Perseus Arm can be seen in the direction of the constellation of Perseus from Earth where you'll find Messier objects such as the Crab Nebula as well as open clusters M38 and M52 marking its path.

**Orion-Cygnus Arm**
This minor spiral arm which measures around 3,500 light years across and some 10,000 light years in length is where our home can be found - nestled in the Orion Arm, or Orion Spur, about 26,000 light years from our galaxy's centre.

## Barred-spiral

The Milky Way's arms have to start somewhere and that's from its glowing bright centre that hosts Sagittarius A* - a supermassive black hole around 4 million times the mass of our Sun that throws out intense emissions in the radio wavebands. Most galaxies feature a round bulge at their centres - but not the Milky Way according to experts. They figure that our galaxy's past saw it smashing into and merging with galaxies which left it with a pseudobulge. The evidence? A bar that locks across its heart, connecting the galaxy's arms; a feature that is hotly debated by galactic astronomers the world over when it comes to agreeing on some of its characteristics as well as its very existence.

With estimates at around 3,300 to 16,000 light years for its halfway point, some astronomers are wondering if this feature might possess two bars nestled within one another. Whereas some think that our Milky Way doesn't have a bar at all. However, for now astronomers have thrown our mysterious galaxy into the barred-spiral category - that's your standard spiral galaxy with a bar wedged across its centre.

# Cosmic rays

Wherever you are in the Milky Way, you are likely to be confronted by cosmic rays; those high-energy particles that seem to race at breakneck speeds from every direction. They come from the stars but most of them are thrown out in supernova explosions. Since they come from stars, our Sun is no exception and cosmic rays that stream through the Solar System come from our star as well as the Milky Way itself.

Contact with cosmic rays would be fatal for humans on Earth but fortunately we have a barrier to stop most of them from reaching us - our planet's magnetic shield, also known as its magnetosphere. However, recent research suggests that the cosmic rays that come from other parts of the Milky Way galaxy are actually affecting our weather and climate despite being refused access through Earth's atmosphere.

Making its way further and further from us all of the time on its trek through interstellar space, the Voyager 1 spacecraft is equipped with a Cosmic Ray Subsystem intent on finding out all of the things we don't know about them - from their life history through to their dynamics in galaxies in general.

Shown in blue, dark matter can be seen here enveloping the inner region of Abell 1689, a cluster of galaxies around 2.2 billion light years away

## Dark matter

You most likely know dark matter as the elusive material we've never clapped eyes on that seems to hide most secrets about itself quite well in the process. It neither absorbs nor emits light of any wavelength, making itself not just invisible to our eyes but also to a number of both ground and space-based telescopes.

However, dark matter is not *that* clever. In the Thirties, astronomers realised that the masses of some astronomical objects – in particular galaxies – don't quite tally up with the masses of the stars, gas and dust that they contain. In short, galaxies were missing mass and dark matter is thought to be the culprit, making up about 27 per cent of the total content of the cosmos.

While it seems to be an elusive beast – with the scientific community on a hunt to track the particles down – dark matter makes its presence felt in other ways. It plays around with the rotational speeds and hot gases of galaxies as well as magnifying clusters of galaxies by using their gravity, in what we refer to as gravitational lensing. To boot, these activities are happening not just inside our galaxy, but outside it too.

## Exoplanets by numbers

**20** *Twenty percent of Sun-like stars in the Milky Way could have Earth-sized planets favourable for life*

**400 billion** Our galaxy could contain as many as 400 billion exoplanets

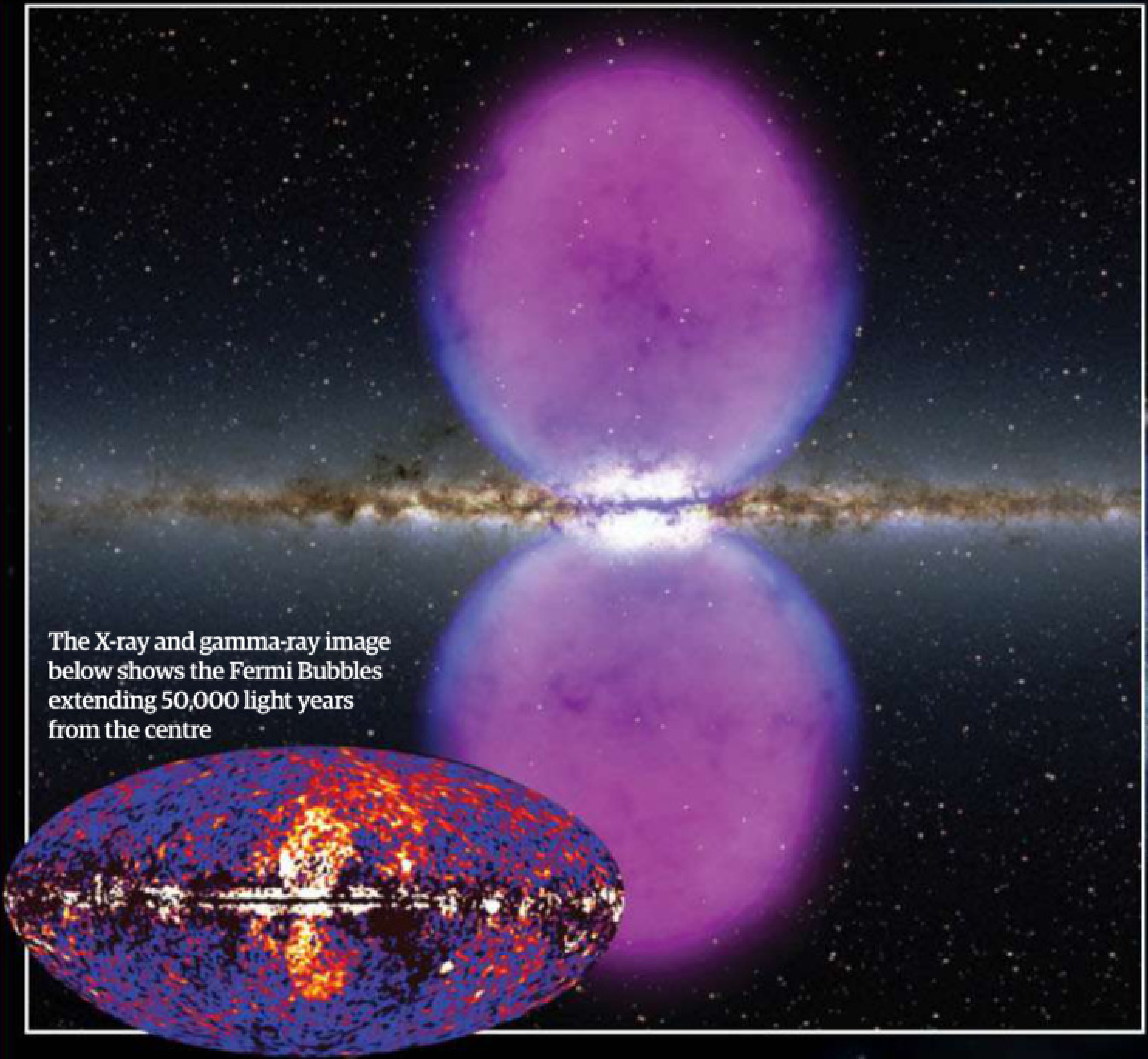
**3,568** The Kepler Space Telescope has uncovered exactly 3,568 candidate planets as of 4 November 2013 – in our galaxy alone!

**2018** *Marks the year that our next exoplanet hunter, the James Webb Space Telescope, will be launched*

**4.37** *At around 4.37 light years away, Alpha Centauri Bb will be the closest exoplanet to us, if confirmed*

**1,000** To date, over 1,000 planets have been found in 794 planetary systems in the Milky Way

**175** 175 of the 794 planetary systems found hold more than one world



The X-ray and gamma-ray image below shows the Fermi Bubbles extending 50,000 light years from the centre

## Fermi bubbles

Deep at the heart of the Milky Way lurks the supermassive black hole Sagittarius A* which feeds on gas and dust that strays into its path. However, what NASA's Fermi Telescope found right at our galaxy's centre surprised us all; a previously unseen structure spanning some 50,000 light years and glowing in X-rays and gamma rays.

In these lobes, thought to have been made a few million years ago, the gamma-ray hunter had found evidence that suggests that our galaxy had a somewhat active past before settling down for the comparatively quiet life it leads now. What precisely caused these great outbursts – which span more than half of our visible night sky – isn't quite certain though. While some astronomers have grabbed hold of the possibility of a quasar-style outburst from a highly energetic central black hole, others, quite recently – with the help of a collaboration between the Parkes Radio Telescope in Australia and space-bound Wilkinson Microwave Anisotropy Probe (WMAP) – are suspecting, along with the detection of microwave wavebands, intense star formation that pumps matter characteristic of magnetic fields into its surroundings. Not quite happy with this explanation either, some astrophysicists reckon that the collision between dark matter particles and its antiparticle – resulting in an enormous annihilation – might in part be responsible for the mysterious lobes.

## Globular clusters

Whizzing around our Milky Way are a host of pint-sized collections of tightly bound stars known as globular clusters. These gatherings of hundreds of thousands of stars are fairly common with up to 158 of them known to be orbiting our galaxy. While we're still not fully sure of how these clusters came about or what part they play in the evolution of these great structures, what we do know is that they tell the tale of star formation as they contain some of the oldest stars in the Milky Way.

An impressive 90 per cent of the globular clusters we know to be hanging around our galaxy rest around 100,000 light years from its centre and can be found in its halo – an area free of dust and found to be hanging on to old, lower metallicity stars that are often quite red in colour.

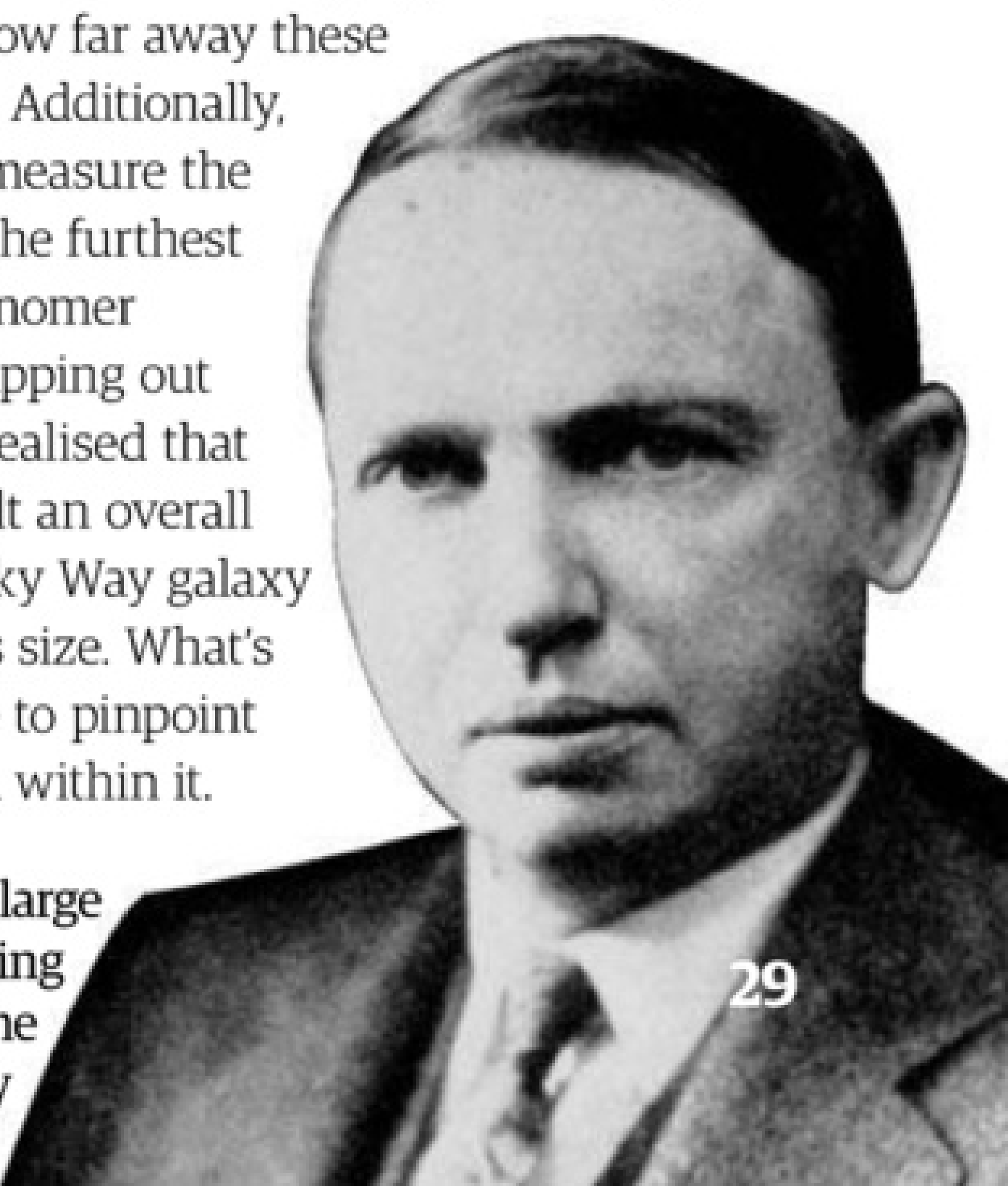
Our galaxy is flanked by smaller dwarf galaxies. One such satellite galaxy is the elliptical loop-shaped Sagittarius Dwarf that holds on to four globular clusters. What's interesting about this galaxy is that it appears to be eager to donate its clusters to the Milky Way as is the hotly debated Canis Major Dwarf that hangs close to our galaxy. Could this be how the Milky Way acquired its store of clusters in the past? Astronomers believe that it's feasible.

Globular clusters contain hundreds of thousands of stars

# Harlow Shapley

If there's one person that could have pinpointed our place in the Milky Way galaxy, it was American astronomer Harlow Shapley. And that's exactly what he did with the help of globular clusters that he began studying in 1914, plus a 1.5-metre (60-inch) reflecting telescope at the Mount Wilson Observatory in California.

Armed with what was hailed as the world's most powerful telescope at the time, Shapley wondered how far away the tightly bound clusters of stars that he could see through his eyepiece were. He got his answer with the help of the highly luminous Cepheid variable stars, which, as discovered by astronomer Henrietta Swan Leavitt, were found to give a period of variable brightness over time. Using this method Shapley was able to measure the distances to these stars. And, given that these Cepheids were nestled in the globular clusters he was studying, he could get an inkling as to how far away these clusters were, too. Additionally, finding a way to measure the distance to even the furthest clusters, the astronomer found himself mapping out his findings and realised that he had in fact built an overall picture of the Milky Way galaxy and its monstrous size. What's more, he was able to pinpoint our Sun's position within it.



Shapley played a large role in pinpointing our place in the Milky Way

# Interstellar medium

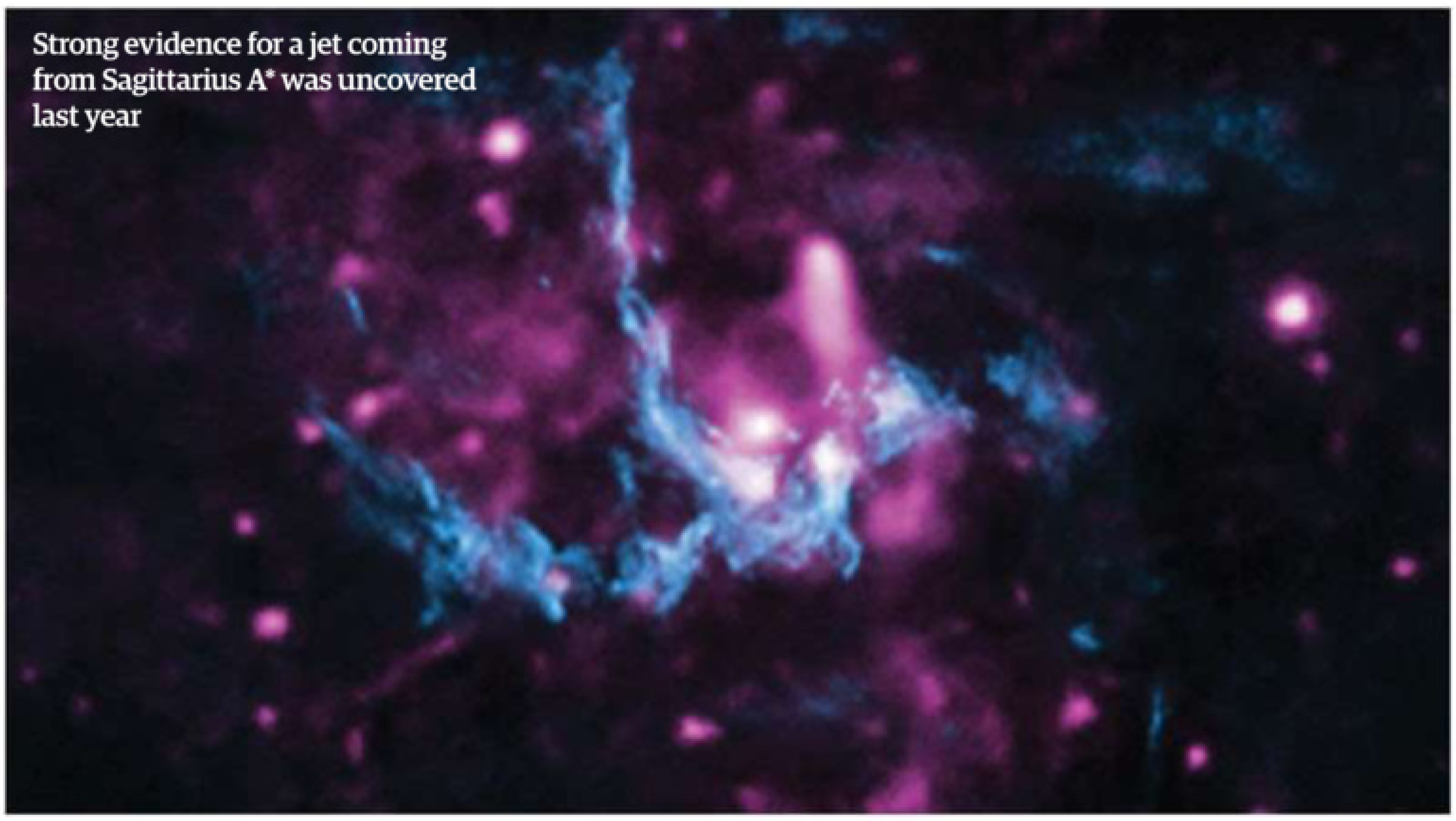
It might be called space, but those regions between the stars in our galaxy are not completely empty. It's often filled with gas and dust but that's not all, magnetic fields and charged particles can also be found to be lurking. We call this the interstellar medium and it makes up a small fraction of our galaxy's visible matter – somewhere between 10 and 15 per cent of its mass.

While only a small one per cent is dust, with the rest being interstellar gas, astronomers still find it to be a bit of a hindrance – especially since it blocks out a lot of starlight. Without it, we would be able to peer through the galaxy's entire 100,000 light year disc – much more than the 6,000 light years we can currently see.

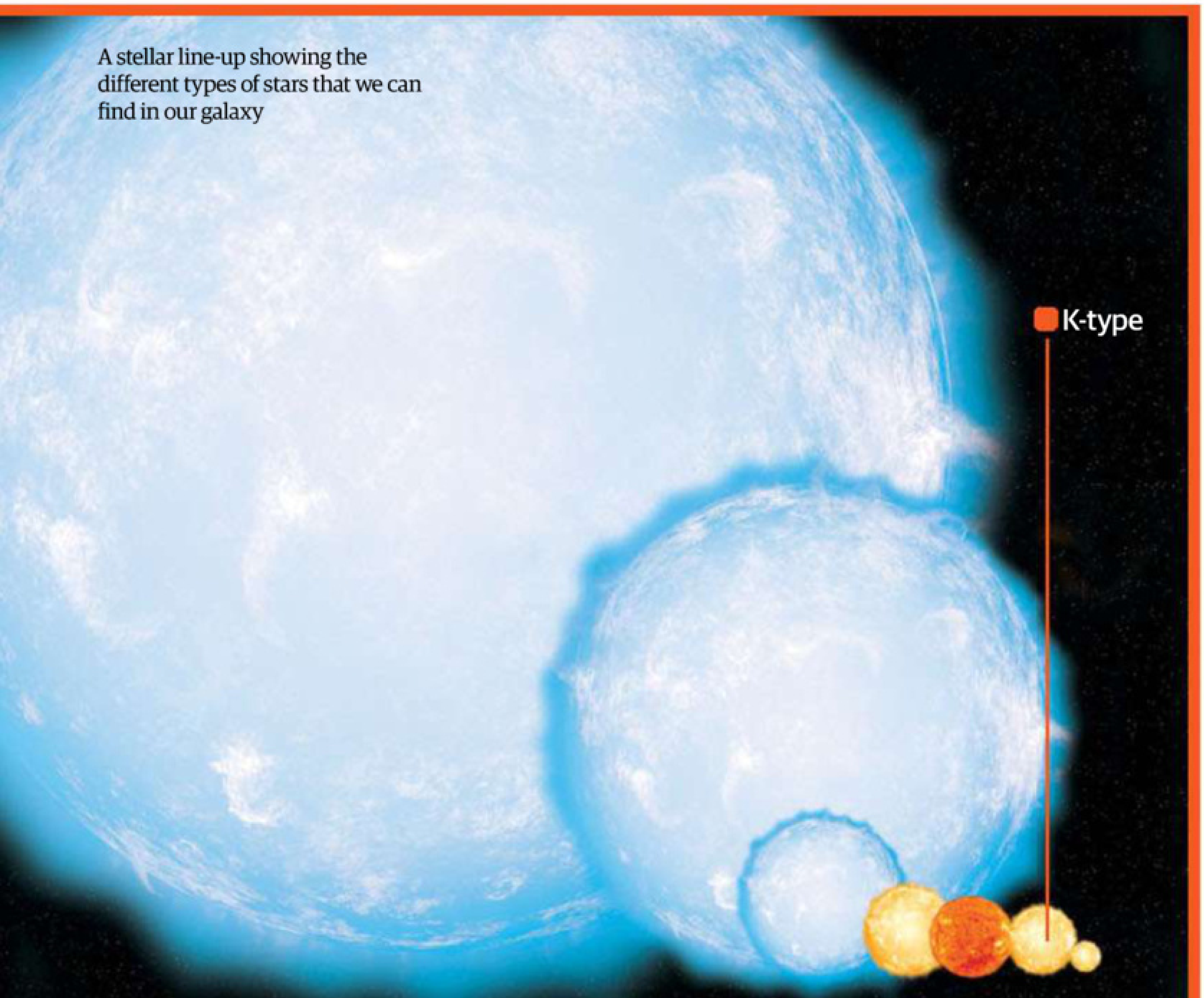
# Jets

As well as feeding on gas and dust, our Milky Way's black hole likes to shoot out a torrent of highly energetic particles. Astronomers had long suspected that Sagittarius A* was hiding something from us and now, as of late 2013, we have evidence thanks to the efforts of NASA's Chandra X-ray Observatory and the ground-based Very Large Array radio telescope. Jets can be found throughout the universe on both large and small scales - they can be found emanating from young stars to black holes thousands of times larger than the Milky Way's. Their role is important, as, without them, the birth of young stars wouldn't be regulated.

While Sagittarius A* likes to consume everything, like all black holes, it doesn't eat as much. This means that the jet thrown out isn't very strong at all, making it difficult to detect. That is, until now.



Strong evidence for a jet coming from Sagittarius A* was uncovered last year



A stellar line-up showing the different types of stars that we can find in our galaxy

# K-type stars

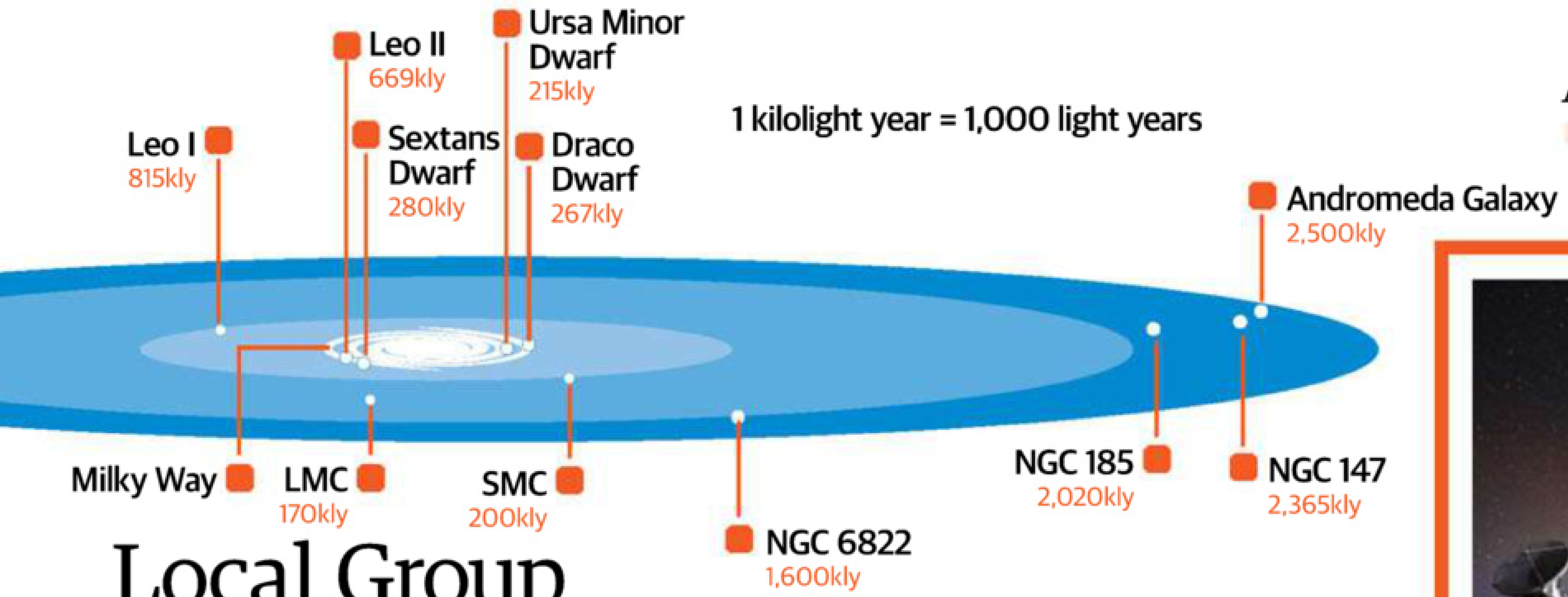
Between our G-type Sun and the red dwarf M-types rest the K-type stars. Intermediate in size between the two aforementioned extremes and glowing with a distinct orange colour, K-types are around 0.6 to 0.9 times the mass of the Sun; almost reaching a similar mass to our star and sizzling with a surface temperature somewhere between 3,600 and 4,900 degrees Celsius (6,500 and 8,850 degrees Fahrenheit).

However, although they are similar to our star, these orange dwarfs are in fact a bit more stable than our Sun - being able to last the distance for 15 to 30 billion years in comparison to our Sun's 10 billion before it swells into a red giant. What this essentially means is that these stars are of particular interest when it comes to hunting for extraterrestrial life. And, lucky for us they're quite plentiful at around three to four times as abundant as stars like our Sun, making finding that holy grail of a rocky, Earth-like world that little bit easier.

# Naked eye

That dusty band of stars that you can find snaking across the night sky isn't a trick of your eyes, it's none other than the Milky Way. The splash of stars that makes a hazy white path through a range of around 30 constellations in both the northern and southern hemispheres with the brightest part of the galaxy - its luminous centre - lacing through the constellation Sagittarius.

The individual stars that you are able to pick out with the naked eye belong to our galaxy, but the band of white light that's about 30 degrees wide arching across the sky is what both professional and amateur astronomers alike refer to as the actual Milky Way. This light - which is thrown out by stars and material - is something that you're unlikely to be able to resolve into stars with your eyes alone. Still, if you're in a dark spot, then our galaxy will certainly give you an eyeful of uncountable stars and even more so with a telescope or binoculars!



# Local Group

We know we're not the only galaxy in the universe. Just a quick glance at the Hubble Deep Field - an image snapped by the Hubble Space Telescope that's crammed with galaxies of all different shapes, sizes and distances along with the Andromeda Galaxy - offers plenty of evidence for that. Stretching some ten megalight years into space we find ourselves as part of a membership along with more than 54 other galaxies; known as the Local Group. The biggest galaxies dominating the party are our own galaxy and our closest spiral, Andromeda, followed by the only unbarred spiral in the group, the Triangulum Galaxy. Flocked by their satellite galaxies along with a menagerie of galactic dwarfs, the members of the Local Group are continually dispersing at a rate of almost 65 kilometres (40 miles) per second. This grouping of galaxies is also nestled within the 110 million light year across Virgo Supercluster.

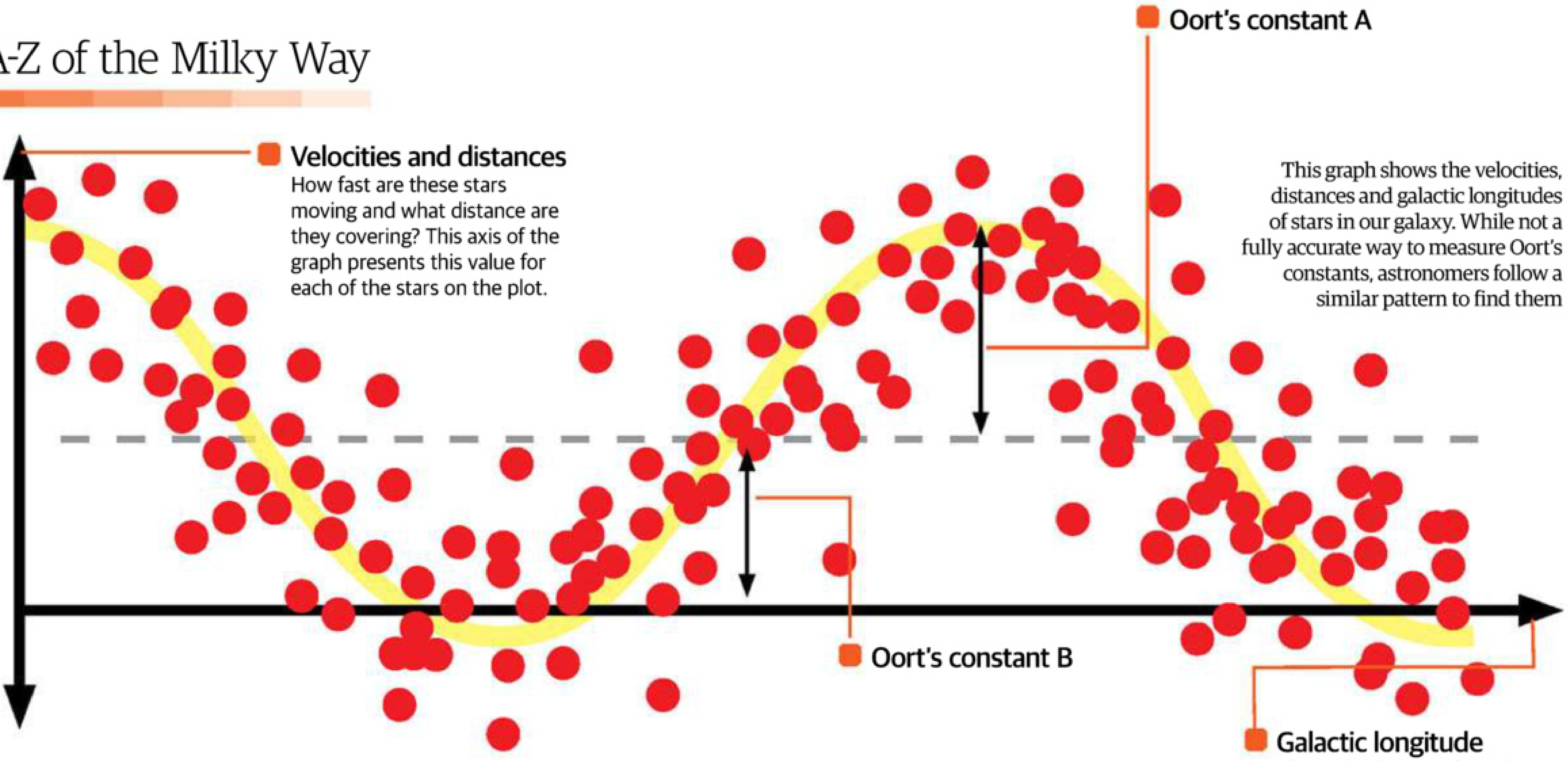
## Magellanic Clouds

If you look up in clear southern hemisphere skies you'll spot two of our galaxy's neighbours, the Large Magellanic Cloud and the Small Magellanic Cloud - they can be found around 160,000 and 200,000 light years away, respectively. They might seem like the shattered pieces of our Milky Way, but a closer look reveals them as irregularly shaped dwarf galaxies with bar structures wedged across their centres. And even closer inspection has led astronomers to think that the smaller of the two may be split into two, dubbing the extra piece as the Mini Magellanic Cloud.

Since they hug our galaxy quite closely, both have been tugged at by the gravity of the Milky Way but our galaxy hasn't got off scot-free, the tidal interactions have also pulled at the Milky Way's centre, warping its disc to a noticeable extent. Trails of hydrogen gas can be found chaining the Magellanic Clouds and our galaxy together but, despite holding on to each other in such a fashion, they differ wildly.

Both dwarf galaxies are brimming with hydrogen and helium and are home to metal-poor stars - those devoid of elements such as carbon, nitrogen, oxygen and neon. The Milky Way is the complete opposite, supporting a menagerie of metal-rich and metal-poor stars, a witness to a long star formation history, while it's also teeming with clumps of dust and gas.

> "Trails of hydrogen gas can be found chaining the Magellanic Clouds and our galaxy together"



**Velocities and distances**
How fast are these stars moving and what distance are they covering? This axis of the graph presents this value for each of the stars on the plot.

**Oort's constant A**

This graph shows the velocities, distances and galactic longitudes of stars in our galaxy. While not a fully accurate way to measure Oort's constants, astronomers follow a similar pattern to find them

**Oort's constant B**

**Galactic longitude**
This is the distance from the Sun through to the Milky Way's centre along our galaxy's plane.

# Oort's constants

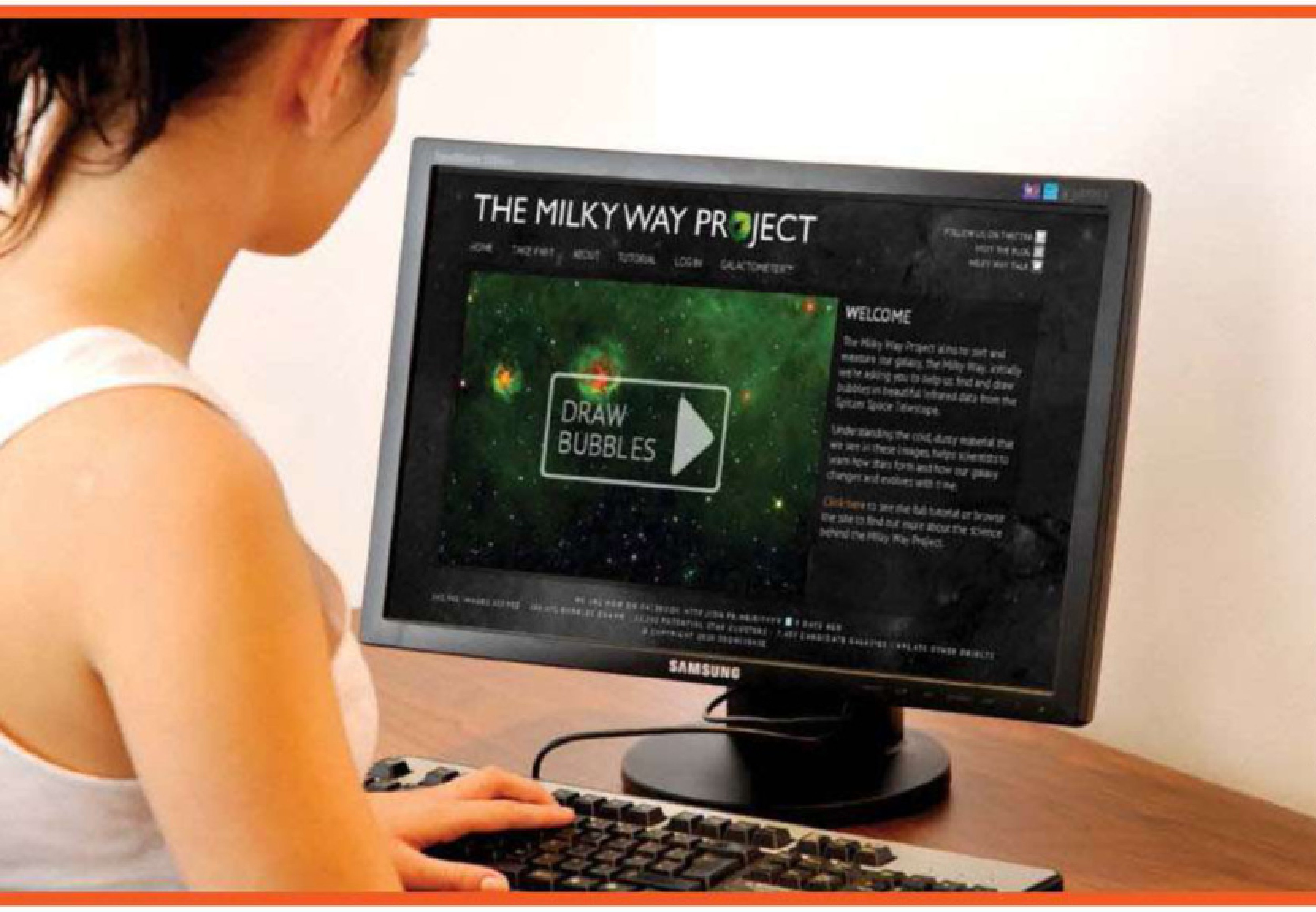
We know that galaxies can't stay still; they can be found to be moving away from us as well as crashing into each other and warping their structures in the process. However, they're also moving in another way - they're rotating - and the Milky Way is no exception.

The way that everything in the galaxy moves around its centre is not quite what you'd expect. Our Milky Way moves in mysterious ways preferring to rotate like a fluid rather than the solid that it seems more akin to.

It was Jan Oort who first recognised this in 1927. The Dutch astronomer - who you probably recognise as playing a massive part in suspecting the Oort cloud; the swarm of icy cometary bodies surrounding the Solar System - got a helping hand from a small fraction of stars in our Sun's neighbourhood. He not only found that our galaxy is rotating, but stars further out from its centre are taking longer to complete one lap compared to those who have a shorter distance to travel at the centre and so can just whip around relatively quickly.

Imagine a star between us and the galaxy's centre. Given how the stars move, this star will not always be between us and the centre of the galaxy and it will not always be at the same distance and will continue to get further and further away from us. This star has a motion relative to us. And it is here that Oort gave us Oort's constants; a couple of measurements that are the bones of the relative orbital motions of our Sun and stars in our very own neck of the galactic woods. Constant A - the shear of the galaxy - is measured at around 14.8 kilometres (9.2 miles) per second for every 3,260 light years, whereas the second, Constant B, tells you about a star's tendency to orbit around its chosen point in the galaxy's disc. Oort measured -12.4 kilometres (-7.7 miles) per second for every 3,260 light years here.

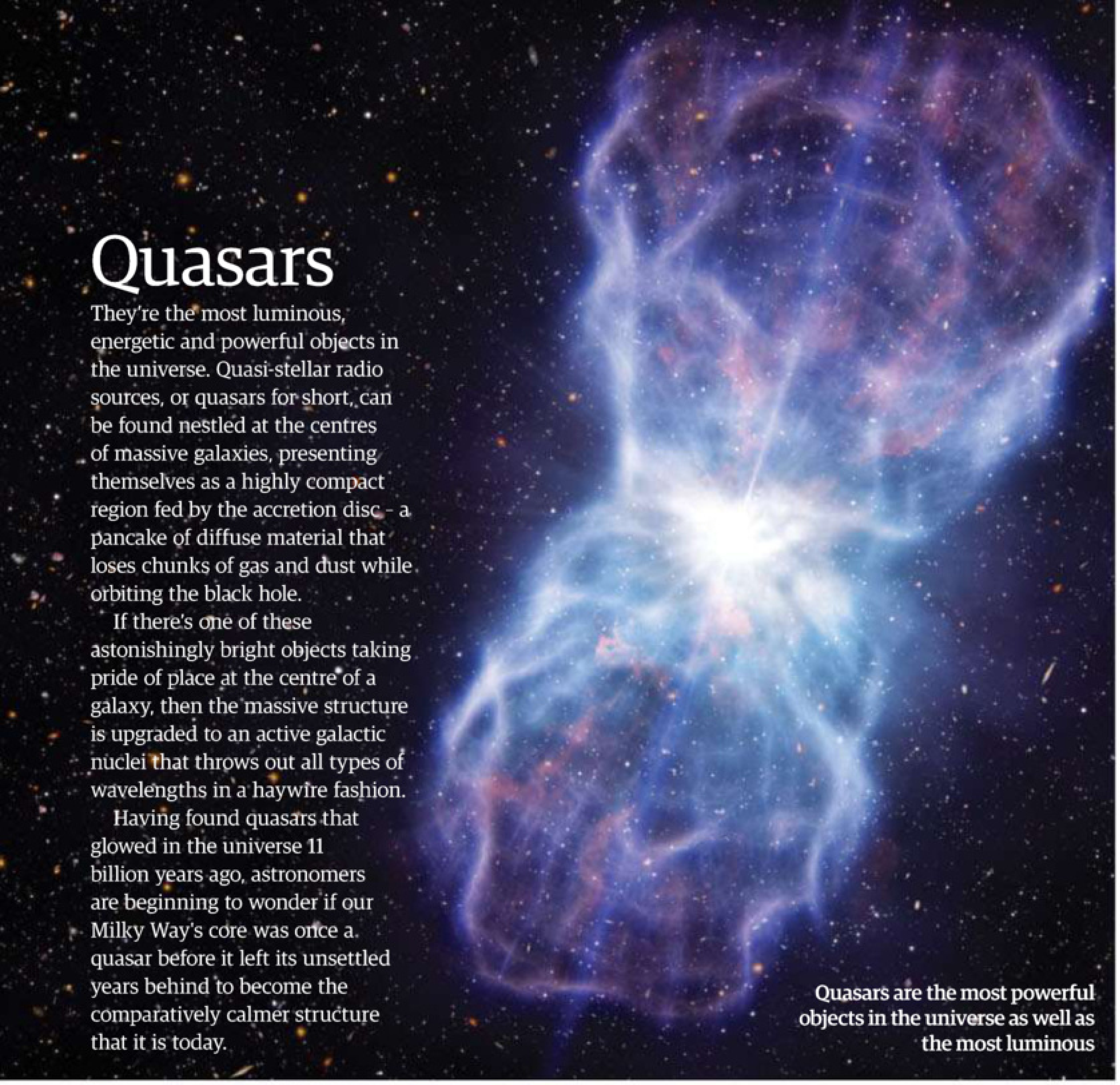
"Our Milky Way moves in mysterious ways preferring to rotate like a fluid"



## Project Milky Way

The Milky Way needs you! And that's why the people of the Citizen Science Alliance behind the Milky Way Project, which forms part of the Zooniverse web portal alongside the likes of Galaxy Zoo, Planet Hunters and SETILive, have made it easy for you to just log on and classify the weird and wonderful objects that our galaxy has to offer. Using infrared images snapped by the NASA Spitzer Space Telescope and Herschel Space Observatory, the name of the game is to help scientists identify bubbles in the Milky Way galaxy by simply drawing a circle around them for experts to have a closer look at. These bubbles could be the result of the light of massive, young stars creating brilliant shocks in the space gas found between them.

But that's not all - from the get-go you're likely to come across wispy green material found near these bubbles thought to be possible sites of star formation, and clusters of stars among other objects such as the remnants of supernovas and newly discovered galaxies as well as the mysterious fuzzy red objects that seem to appear. Head over to www.milkywayproject.org to get started!



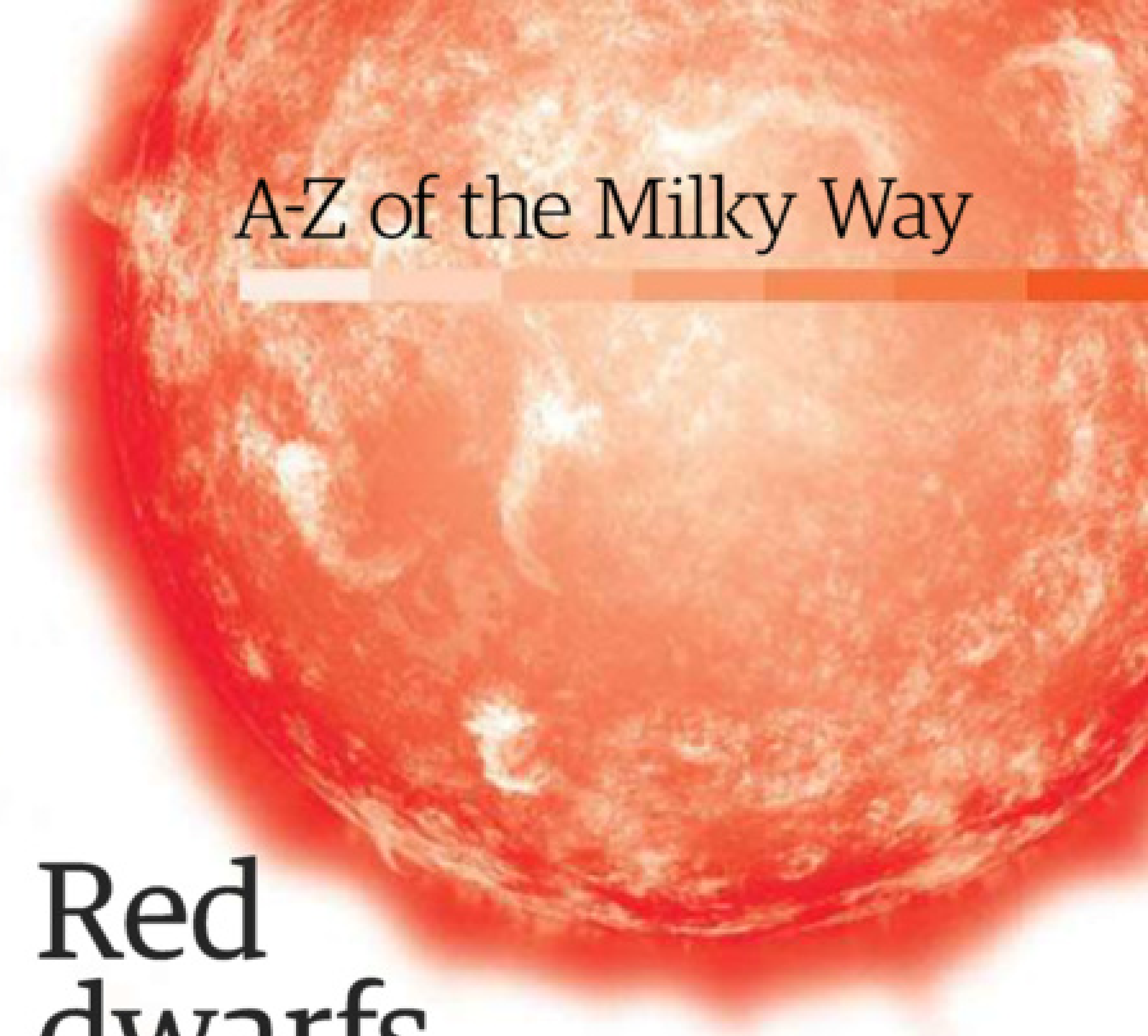
# Quasars

They're the most luminous, energetic and powerful objects in the universe. Quasi-stellar radio sources, or quasars for short, can be found nestled at the centres of massive galaxies, presenting themselves as a highly compact region fed by the accretion disc - a pancake of diffuse material that loses chunks of gas and dust while orbiting the black hole.

If there's one of these astonishingly bright objects taking pride of place at the centre of a galaxy, then the massive structure is upgraded to an active galactic nuclei that throws out all types of wavelengths in a haywire fashion.

Having found quasars that glowed in the universe 11 billion years ago, astronomers are beginning to wonder if our Milky Way's core was once a quasar before it left its unsettled years behind to become the comparatively calmer structure that it is today.

**Quasars are the most powerful objects in the universe as well as the most luminous**

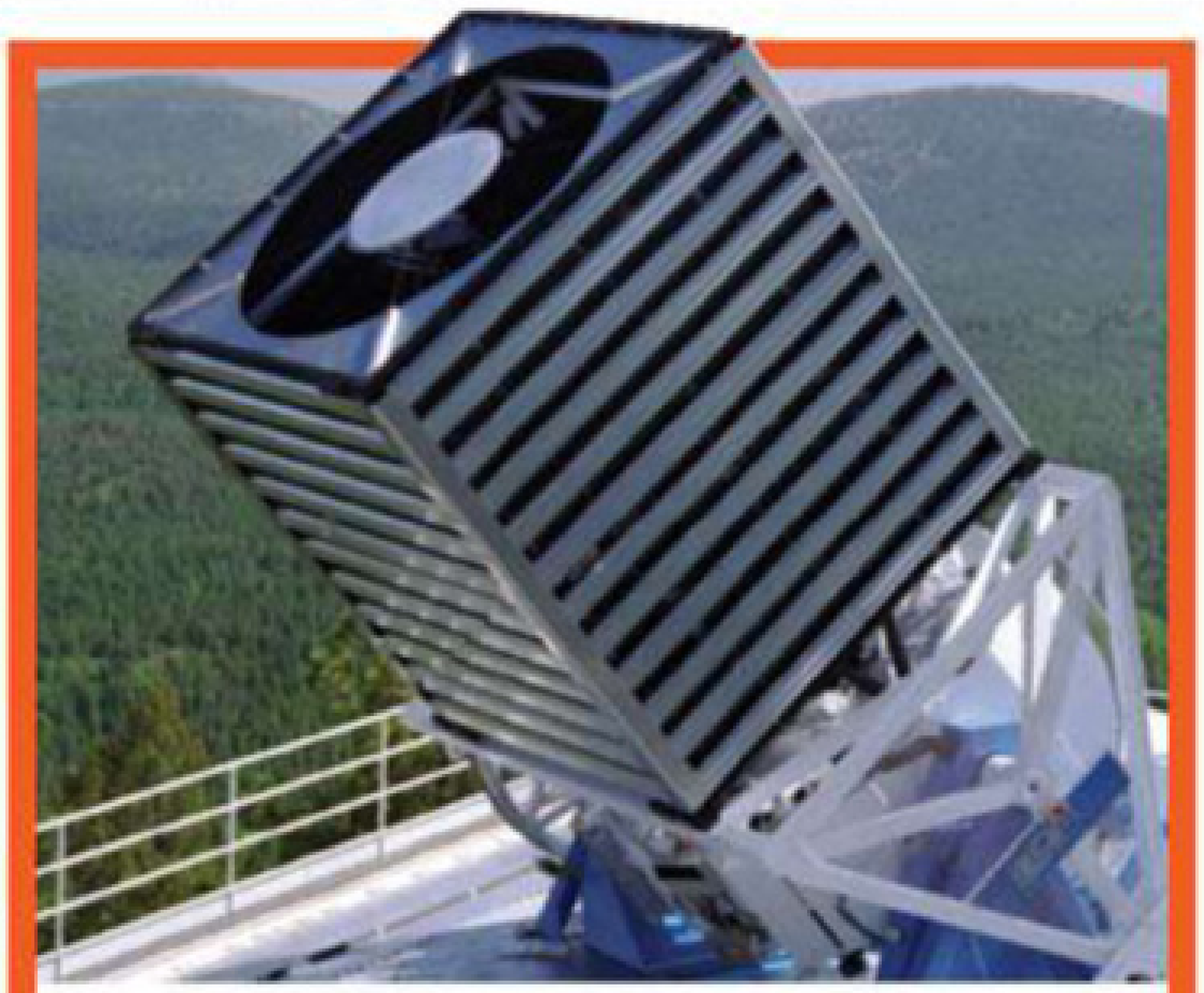


# Red dwarfs

Everything about red dwarfs is low. They have very low mass, only reaching about half the mass of our Sun, and low temperatures of less than 3,700 degrees Celsius (6,700 degrees Fahrenheit). As a result their cores generate energy at a very low rate, putting out as little as 1/10,000 the light thrown out by the Sun.

However, a look around the Milky Way reveals that they are the most common type of stars here, making up a good three quarters of the galaxy's stellar content. In our part of the universe, we're surrounded by mostly red dwarfs with the closest being Proxima Centauri - 4.24 light years from us - and 20 of the next 30 closest stars are also red dwarfs.

These stars, which are the hangers-on of the star world, like to take their time - trillions of years to be exact - when it comes to using up their hydrogen fuel, meaning that they can outlive the universe without too much trouble.



The Sloan Digital Sky Survey is probing the Milky Way for its secrets

# Sloan Digital Sky Survey

The Milky Way-mapping Sloan Digital Sky Survey (SDSS) in New Mexico, USA, has been exploring the Milky Way and the galaxies beyond it since the year 2000 to uncover facts about its early years, what it looks like now and its future. In 2005 its Sloan Extension for Galactic Understanding and Exploration, or SEGUE, survey obtained spectra of 240,000 stars to create a detailed three-dimensional map of our galaxy. The SDSS continues to track down supernovas, monitor thousands of bright stars for exoplanets and brown dwarfs and penetrate the galaxy's obscuring dust to grab surveys of 100,000 red giants as well as getting an even better map of the Milky Way with the help of SEGUE-2.

What we expect to happen as the Milky Way and Andromeda approach each other to collide

# Tidal forces

We see it as the smash-up of all smash-ups - the inevitable collision between our Milky Way and the neighbouring spiral, Andromeda. We're used to galaxies moving away rather than heading for us, but the truth is that they are both racing off and crashing into one another more often than you might think.

Despite Andromeda heading towards us at around 400,000 kilometres (250,000 miles) per hour a collision between the two giants won't happen until about 4 billion years from now. The reason this is going to happen is all down to the gravity of dark matter surrounding the pair, knitting them together so tightly that they resist the expansion of the universe, causing Andromeda to be drawn to us.

When this spectacular collision occurs, tidal forces will create a single elliptical galaxy, kickstarting a great burst of star birth. What's left of our Solar System after our Sun evolves into a swollen red giant will be dealt with by gravitational disturbances, tossing it even further from our galaxy's centre. A few billion years after 'Milkomeda' has been made, our third largest neighbouring structure - the Triangulum Galaxy - will join the party, with tidal forces causing it too to merge.

storemags

The Hubble Space Telescope has uncovered that our galaxy is unique in terms of its formation and evolution

# Unique

Stars? Check. Gas? Check. Dust? Check. Black hole? Check. Ask anyone what they think is the most unique thing about the Milky Way galaxy and they might be stumped for an answer; especially if the most unusual thing that they can think of is that it is the only galaxy - that we currently know of - to host life. While this might be one of the unique things about our home, it's not the only feature.

According to the long-serving Hubble Space Telescope, our Milky Way galaxy is unique in its own right, especially when we look at how it formed and evolved later on. It's a popular theory that spiral galaxies are the result of a cosmic smash-up between galaxies, causing them to morph arms among other weird shapes. However, despite being a spiral galaxy, the Milky Way seems to have been spared most of the drama, avoiding punch-ups between other structures and turning into a spiral all by itself. Clearly this doesn't quite fit our picture of the Milky Way's history and astronomers have to do a bit more work to figure out where our galaxy becomes part of galactic models.

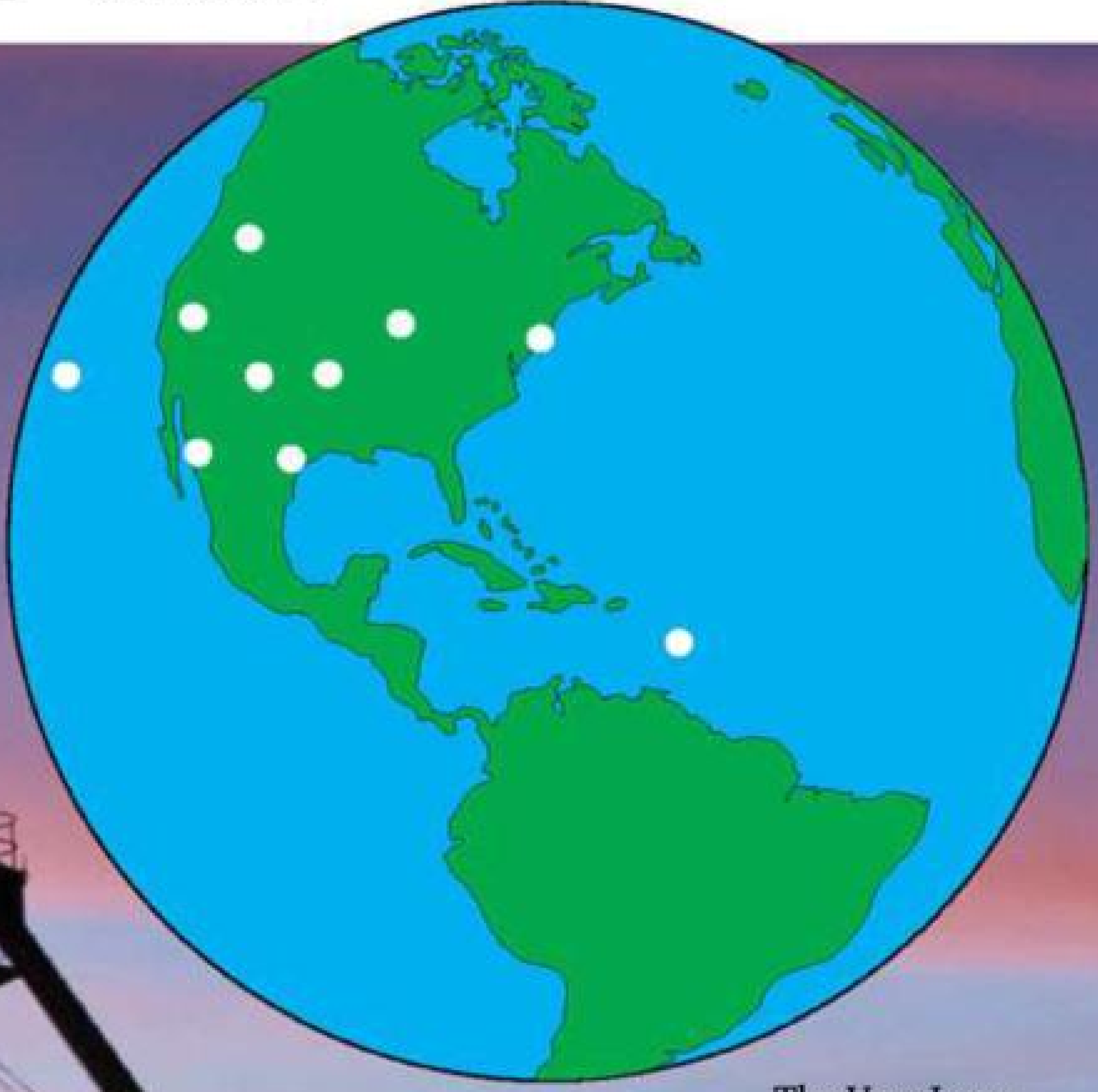
And that's not all, the Milky Way belongs to quite a rare subset among the billions that populate the cosmos. That is, only around four per cent of galaxies are like ours.

# Very Long Baseline Array

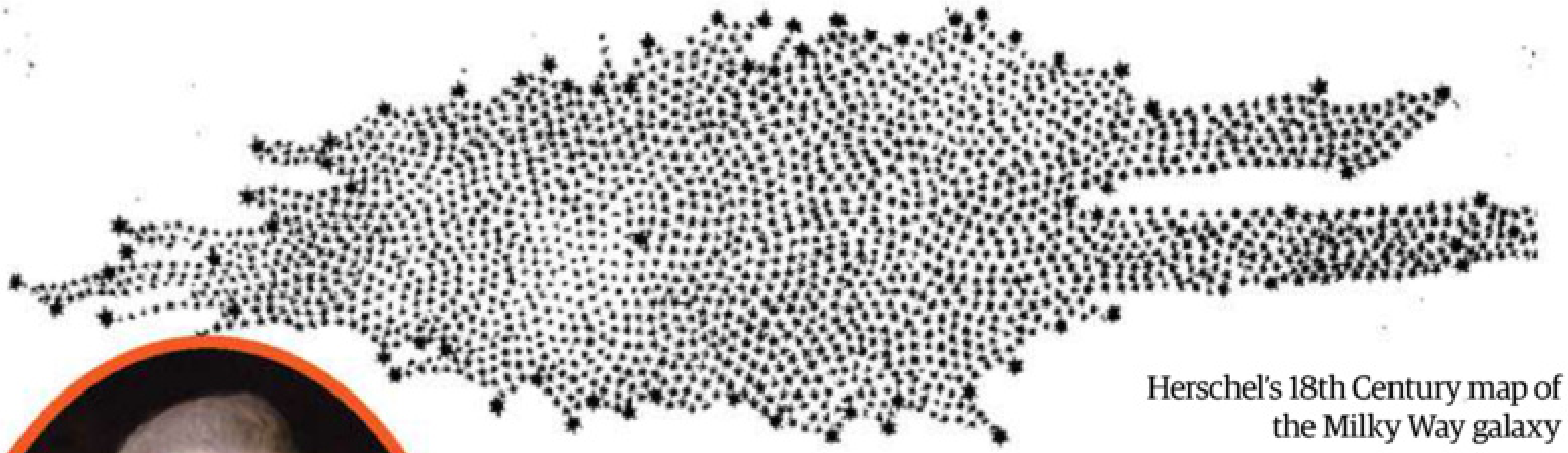
Found at several locations around the United States, ten identical radio telescopes - extending across a range of 8,600 kilometres (5,300 miles) from Mauna Kea in Hawaii to St Croix on the Virgin Islands - have been studying our universe in unison since they became fully operational in 1993. The National Radio Astronomy Observatory's Very Long Baseline Array (VLBA) - which makes its observations at wavelengths anywhere between a tiny three millimetres and 28 centimetres, or frequencies from 0.3 gigahertz to 96 gigahertz - is able to operate in a range that's useful to radio astronomy.

And it puts its ability to great use, looking at the full force packing gamma-ray sources and highly energetic galaxies clutching active galactic nuclei as well as looking at how our Local Group of galaxies were born. But not one to forget the very arms that cradle our own Solar System, the VLBA is also probing the Milky Way for its secrets.

The VLBA has got stuck into its study of the Milky Way, finding that stars at the outermost edge are racing around the galactic centre at around 254 kilometres (158 miles) per second and, as of 2010, it began a long-term programme to build a 3D map of our galaxy, locking down much more accurate measurements of its rotation as well as hunting for a more detailed look at how much luminous and dark matter can be found lurking in this majestic structure.



The Very Long Baseline Array, which consists of ten identical radio telescopes across the United States (white dots), continues to probe the Milky Way



Herschel's 18th Century map of the Milky Way galaxy

# William Herschel

Since we have never ventured outside of our galaxy, looking at it from above or below is quite a task. Of course, we might not have been able to blast off into light years of space, but with a long line of past, present and future missions as well as complex models we've got the next best thing by getting a bit of a helping hand in mapping what our home - from its centre to its outer edges - looks like.

Earlier astronomers didn't have such a luxury. So spare a thought for William Herschel, who, in the 1780s, counted all of the stars he could see with his telescope in more than 600 different locations in the night sky. Incorrectly thinking that all of the stars he could see had the same brightness, he calculated the distance to each of them. And, using his measurements he made a map of the sky according to the number of stars he counted and their distances. He even managed to plot where he thought the Sun should be - if you look carefully at the map above, you should be able to see a darker spot close to the middle and therefore close to the centre of the Milky Way.

Herschel was right in thinking that our Sun is closer to the centre of our galaxy than its edge. However, not fully aware of the swathes of gas and dust that block out the brightness of stars, he wasn't quite correct in his measurement of our galaxy's size and shape, which he thought was flat. But given his impressive and dedicated measurements, it certainly was a nice try.

This image shows the thousands of movements that the XMM-Newton space telescope makes as it shifts its gaze from one X-ray object to another

## XMM-Newton

Blasting off into space in late 1999, the ESA-owned XMM-Newton spacecraft's goals were simple; get into an elliptical orbit around Earth and hunt for X-ray emissions originating from objects in the universe and attempt to map the mysterious dark matter using a combination of its on-board telescopes, cameras and spectrometers.

It has made several discoveries, including the galaxy cluster XMMXCS 2215-1738, but XMM-Newton has also made our Milky Way a target - in particular, the whirlwind of activity at its centre; the young stars born to dense clusters as well as the stars, molecular clouds and gases found to swirl around our galaxy's black hole.

## Yellow dwarfs

You only need to step outside on a relatively sunny day to be in the presence of a yellow dwarf - our Sun. Our star belongs to the G-type spectral class; these stars can weigh between 0.8 to 1.2 times the mass of the Sun, with a surface temperature between 5,000 to 5,700 degrees Celsius (9,000 to 10,300 degrees Fahrenheit) and they own a core; the powerhouse that converts hydrogen into helium, turning around 4 million tons of matter into energy every second. As a result, stars belonging to the yellow dwarf family, are capable of outshining a good 90 per cent of the other types of stars that populate the Milky Way. However, while they might be brilliant, they aren't very common in our galaxy with as little as 20 per cent found in the Milky Way's great winding spirals.

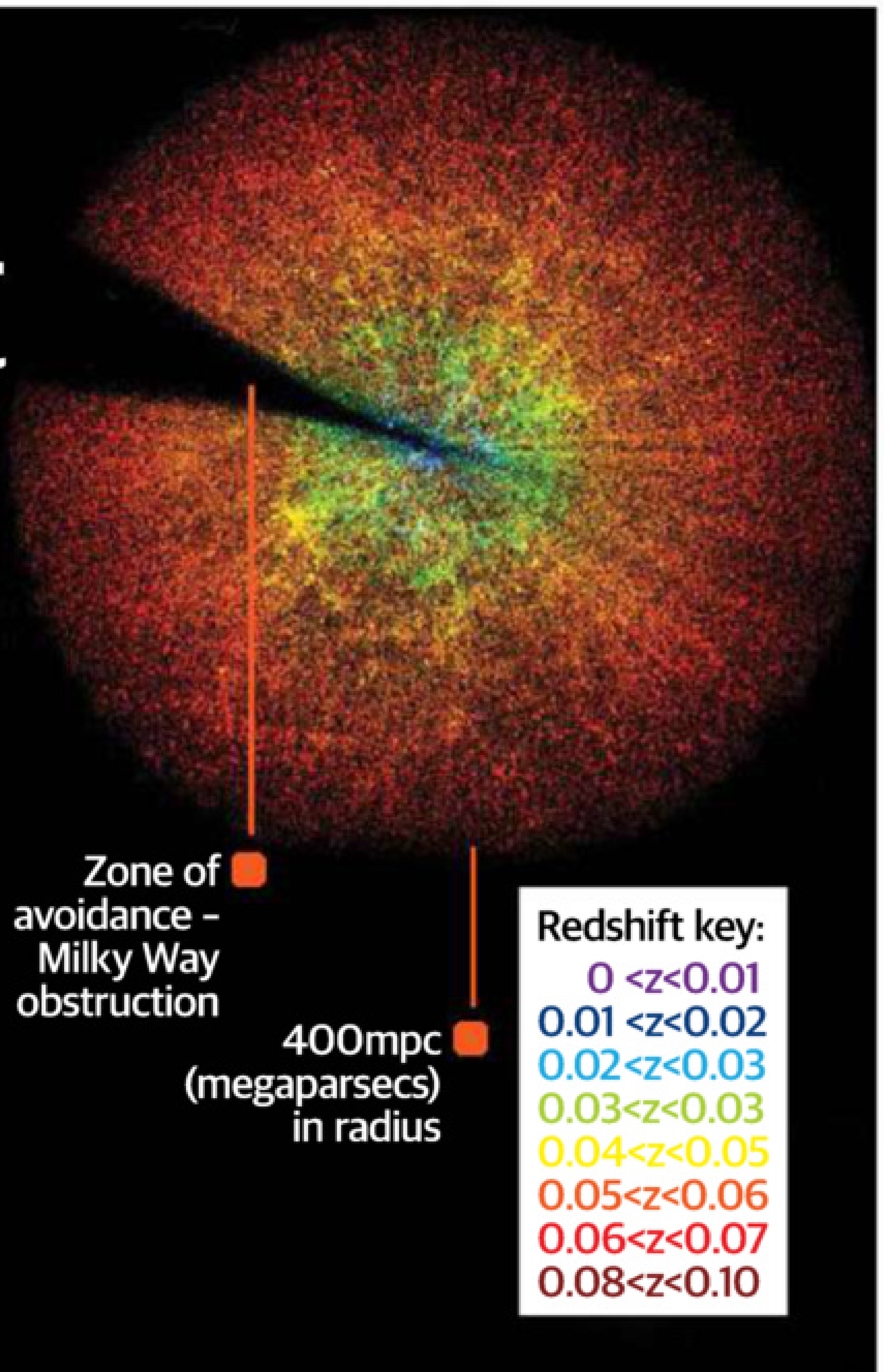
The Sun - and other stars like it, such as 51 Pegasi, Alpha Centauri A and Tau Ceti - might be called yellow dwarfs but this is a relatively loose term. And it's all down to the trickery of our Earth's atmosphere. The scattering of light causes us to see these stars as quite yellow, but in truth they're extremely white only revealing a slight hint of colouring when we escape our planet's somewhat confusing atmosphere.

# z for redshift

When astronomers talk about redshift, they like to refer to it using the letter *z*. And given that it is widely accepted that the universe was the aftermath of the Big Bang - the creator of time and space - redshift is an important concept to astronomers; especially since galaxies, on the whole, are moving away from us as a result.

In a way, we come across a form of redshift in our everyday lives. Everyone has heard the increased pitch of an approaching police car's siren followed by the sharp decrease as the car passes us by, before fading away. What's happening here is that sound waves arrive bunched up to our ears, whereas as the source moves away, these waves become more stretched out. This is called the Doppler effect, and light from galaxies is treated in the same way.

When galaxies move away from us, they are causing the waves of light that they are emitting to become bunched up or compressed - forcing this emission to the redder part of the electromagnetic spectrum. This means that the light is being redshifted and, the redder a galaxy appears, the further it is from the Milky Way galaxy.



These coloured points represent the galaxies moving away from our galaxy. The galaxies that are in the red portion of this spectrum - put together by the Two Micron All Sky Survey (2MASS) - are moving away at higher speeds

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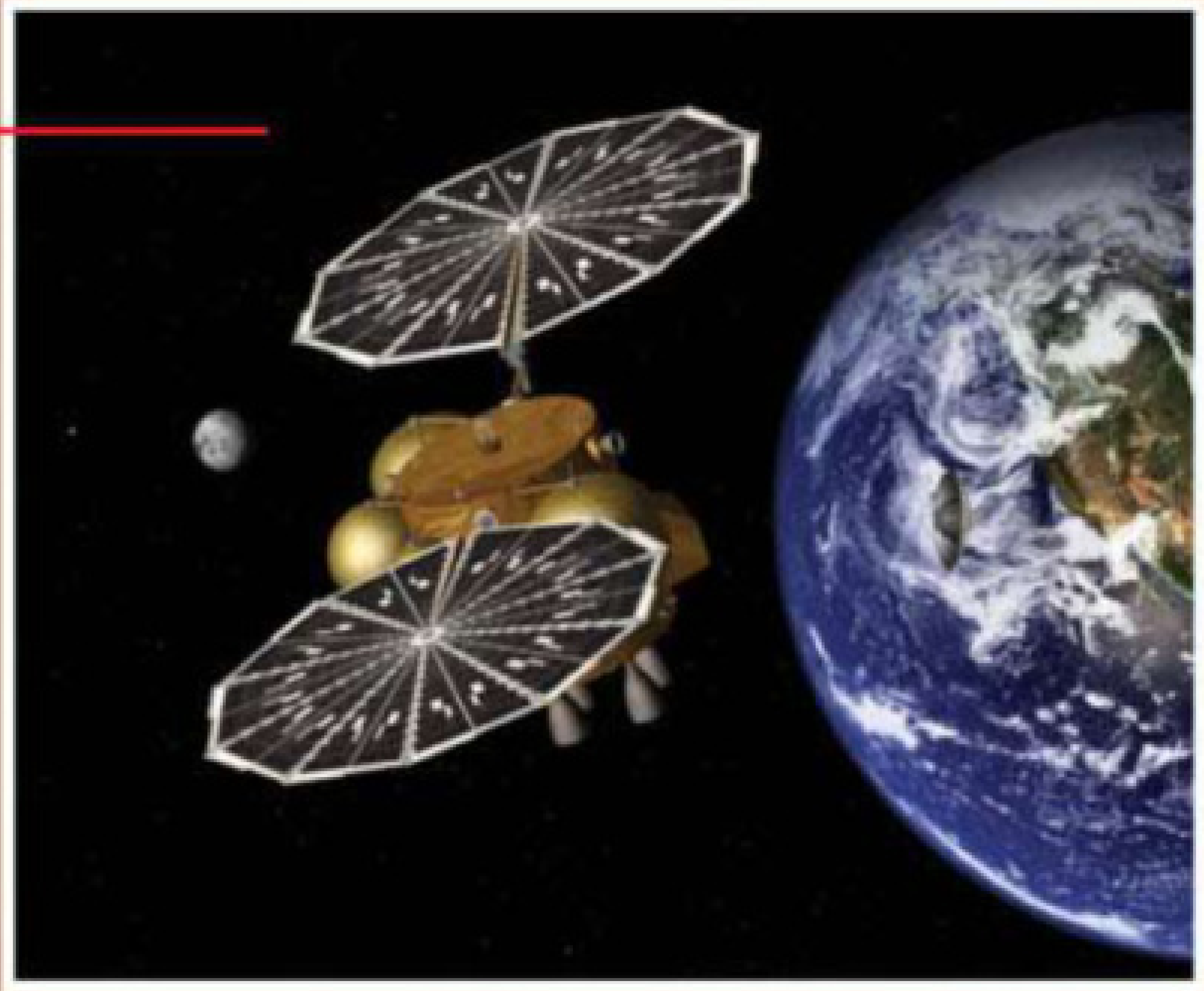
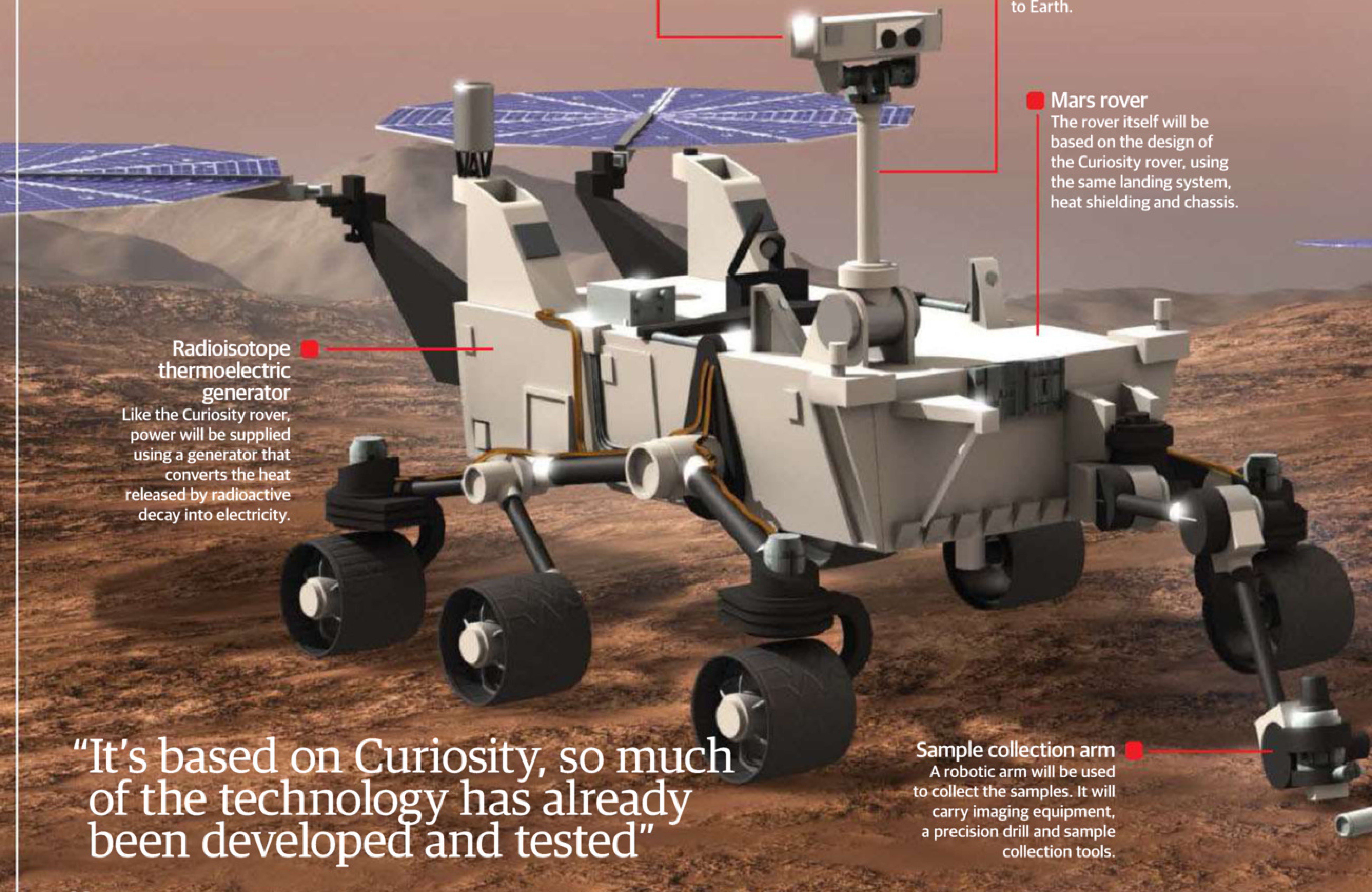
# Mars sample return

## The final step towards bringing Martian rock back to Earth



**Orbiter**
An orbiting spacecraft will be used to retrieve the samples delivered by the Mars Ascent Vehicle, operated remotely with a time-lag to Earth of around 30 minutes.



**Atmosphere sample**
Atmospheric samples may also be taken, enabling more in-depth study than can be achieved with portable equipment on the planet's surface.

**Mast**
A camera and antenna will allow the rover to store and transmit images, communicating with orbiters to relay the data to Earth.

**Mars rover**
The rover itself will be based on the design of the Curiosity rover, using the same landing system, heat shielding and chassis.

**Radioisotope thermoelectric generator**
Like the Curiosity rover, power will be supplied using a generator that converts the heat released by radioactive decay into electricity.

**Sample collection arm**
A robotic arm will be used to collect the samples. It will carry imaging equipment, a precision drill and sample collection tools.

> "It's based on Curiosity, so much of the technology has already been developed and tested"

**Mars Ascent Vehicle**
The samples will be launched into low Mars orbit using a small rocket. New, more efficient engines are in development to minimise the amount of fuel required to launch the samples.

**Soil and rock samples**
A soil sample weighing around 500g (18oz) will be collected from beneath the ground, where any traces of biological components are more likely to have been shielded from radiation damage.

**Landing equipment**
Sophisticated landing gear is in development to protect the MAV as it touches down, using inflatables and breakable legs to absorb the force of the impact.

**Sample cache**
Once the rover has collected and packaged the samples it will return them to a cache for collection by a smaller fetch rover, which will then load them on to the MAV.

## Mars sample return

The Curiosity rover is equipped with an arsenal of technology, but there is a limit as to how much can be achieved remotely. One of the next major steps in the exploration of Mars will be returning samples to Earth for detailed analysis. NASA's proposed Mars sample-return programme aims to do just that.

Several attempts to plan such a mission have failed, like the proposed ExoMars mission for 2018, with cost and technological barriers preventing progress. However, with the continuing success of Curiosity, and the planned Mars 2020 rover mission, new plans for Mars sample-return are underway. The current model involves three separate launches, allowing smaller rockets to be used, and enabling NASA to carefully time each stage of the mission.

The Mars 2020 rover could provide the technology required for the first stage of the project. It will study the history and potential habitability of Mars by analysis of collected rock samples. It's based on Curiosity, so much of the technology has already been developed and tested. What will differ is the scientific payload; it will carry equipment required to retrieve and analyse geological samples, and could be adapted for use in collecting and packaging samples ready for return to Earth.

The rover will contain the equipment required to identify the rock samples, including digital imaging software, and using a combination of infrared, ultraviolet and visible light, samples will be selected based on colour and texture. The external surfaces of Martian rocks have been chemically altered by weathering and radiation, so drilling equipment will be used to access the preserved material at the core where traces of biological material might have had the chance to survive intact.

To prevent contamination of the samples and to protect Earth from any unidentified threat, specialist sample containers are in development. A strong, spherical prototype has already been built by ESA to protect up to 11 sample vials, maintaining them at a constant -10 degrees Celsius (14 degrees Fahrenheit). In order to seal the samples inside the container, remote welding technology is in development, which should allow the rover to completely encase the vials in a biologically impenetrable shell.

In order to return the samples to Earth, two more rockets will be launched around four years after the rover. The first of these will contain the Mars Ascent Vehicle, a small rocket being designed to launch the samples into orbit around Mars. The second is a remote-controlled orbiter to find and collect the samples, before returning them to Earth for analysis.

Once inside Earth's orbit, the payload will either be delivered to the ISS and carried home on a spacecraft from there, or it will re-enter the atmosphere directly. Parachutes are often used to slow a craft on re-entry but given the sensitive nature of the samples extra care will be taken to prevent the container from rupture. A vessel has been developed to house the spheres containing the samples and, although it is still in the prototype phase, it has already passed a 400g shock test and a thermal test simulating a parachute failure.

Planning for this groundbreaking project is ongoing, but with the existing technology in such an advanced state already, we could be bringing samples home from Mars as early as 2022.

© Adrian Mann

# Why do satellites fall?

You can usually see them stuck in orbit, but sometimes they come crashing down to Earth. **All About Space** looks at why satellites fall

"Many satellites burn up during re-entry and don't pose a threat to anyone"

We've all seen it on the news - *satellite falls to its fiery doom*, or - even more pre-emptively - *huge, out-of-fuel satellite set to fall to Earth very soon; location to be decided.* That's just how it is with the majority of satellites - some of them fall from their orbits but, where they aim to come crashing down on our planet's surface is usually something we won't know until it actually happens.

Take the European Space Agency's Gravity field and steady-state Ocean Circulation Explorer, or GOCE, for example. This marvel of technology and engineering began dropping gradually from its orbit over three weeks on an uncontrollable descent towards Earth shortly after running out of fuel in October 2013. As it began to hurtle ever closer to the Earth's atmosphere, there was a media frenzy as GOCE gave into gravity with several reports guessing as to where the 1,100 kilogram (2,425 pound) satellite - which served as its space agency's first Living Planet Programme satellite to map our planet's gravity field - would land.

Its descent might have been uncontrollable but, as it smashed through the layers of our atmosphere, the brunt of re-entry saw the satellite grow a bright smoke tail and break into two before disintegrating near the Falkland Islands. In truth, we were never in any real danger; the re-entry was planned. But what are the logistics behind what causes a satellite to fall?

To understand the answer to this question, we must first understand why they stay on the racetrack that is their orbit. It's down to the balance between two very important factors - the satellite's speed and the gravitational pull between itself and the planet it whips around. And making sure that artificial satellites are prevented from crashing down to Earth involves a bit of know-how on what speed they must hurtle around our planet at.

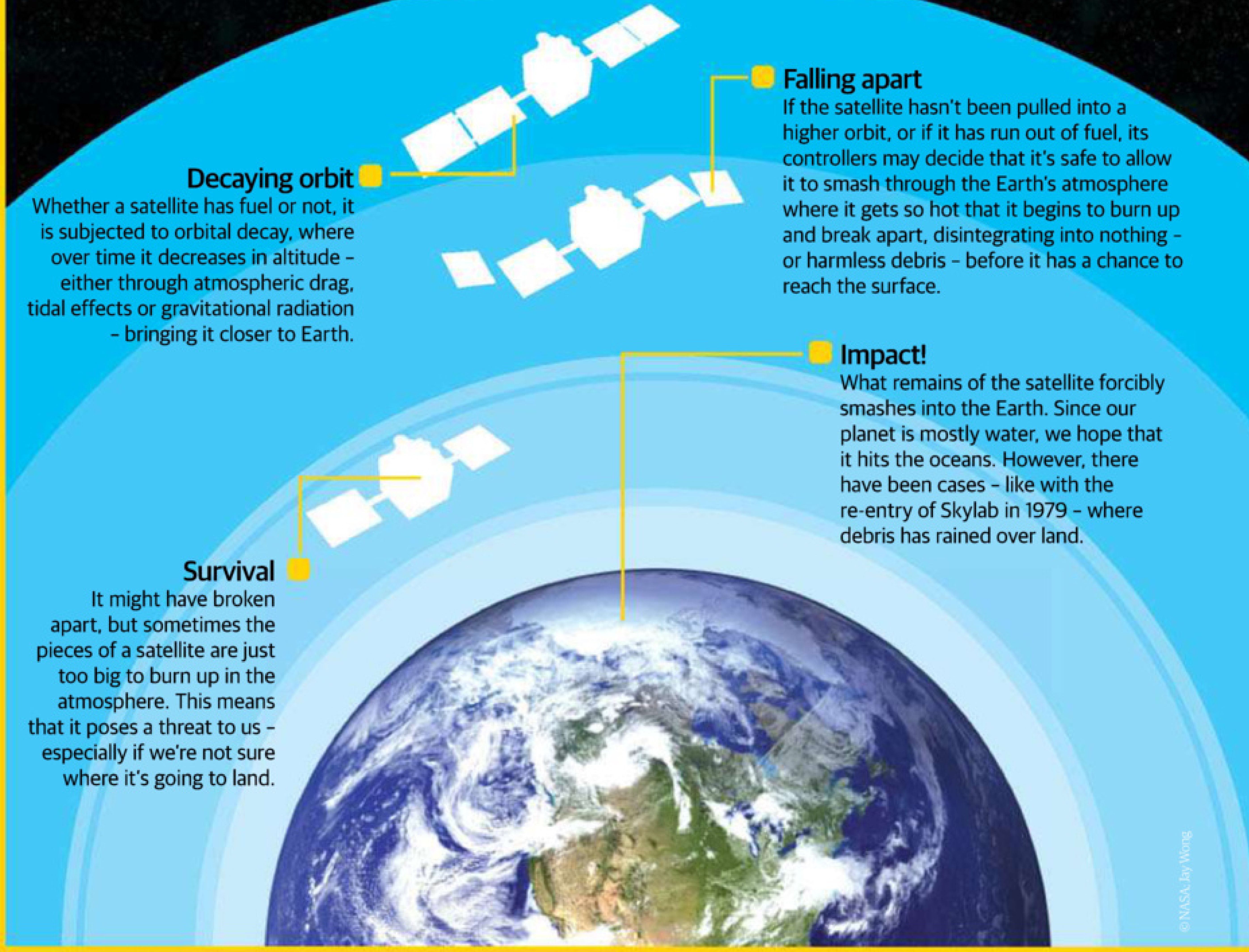
One thing to remember is that a satellite *does* fall towards Earth, it just never falls into Earth when it's in orbit. The Earth curves at around five metres downward for every eight kilometres (16.4 feet for every five miles) along its horizon. What this means is that, in order to stay in space, a satellite must move at a speed that allows it to travel eight kilometres (five miles) before dropping five metres (16.4 feet). As you'd expect, those put in low Earth orbits have to fight much harder against the Earth's influence. So, in comparison to those further out in space, satellites that hug our planet have to move much more rapidly in their orbits.

Earth is surrounded by many artificial objects - from fully functional satellites going about their day-to-day observations to spent boosters - with well over 500,000 bits and pieces in our atmosphere, it really is quite cluttered up there. Satellites that are no longer useful to us are often moved into higher orbits, no longer containing enough fuel to fight against our planet's gravitational tug that attempts to encourage them through the atmospheric barrier. Out of the way of other satellites, it is intended that they will just deteriorate over time in their graveyard orbit. Others are meant to be pulled through the atmosphere, with the majority of them burning up during re-entry - just like GOCE - and not posing a threat to anyone.

There's usually no getting away from the fact that, over time, satellites are subject to orbital decay - that's the prolonged dropping in altitude usually due to a drag put in force by the Earth's atmosphere and most commonly affects low Earth orbiters. It pulls at space stations and shuttles and also brought down the Skylab space station - which didn't break-up as intended with debris striking parts of Australia - and gives scientists a reason to regularly boost the orbit of the Hubble Space Telescope.

The largest fragment of the Skylab station, an oxygen tank, recovered in Australia

## Orbital decay



**Decaying orbit**
Whether a satellite has fuel or not, it is subjected to orbital decay, where over time it decreases in altitude - either through atmospheric drag, tidal effects or gravitational radiation - bringing it closer to Earth.

**Falling apart**
If the satellite hasn't been pulled into a higher orbit, or if it has run out of fuel, its controllers may decide that it's safe to allow it to smash through the Earth's atmosphere where it gets so hot that it begins to burn up and break apart, disintegrating into nothing - or harmless debris - before it has a chance to reach the surface.

**Impact!**
What remains of the satellite forcibly smashes into the Earth. Since our planet is mostly water, we hope that it hits the oceans. However, there have been cases - like with the re-entry of Skylab in 1979 - where debris has rained over land.

**Survival**
It might have broken apart, but sometimes the pieces of a satellite are just too big to burn up in the atmosphere. This means that it poses a threat to us - especially if we're not sure where it's going to land.

© NASA; Jay Wong

# The rise of the Russian space agency

## How Russia took the reins from the Soviet Union to become the world leader in manned exploration

**Written by Jonathan O'Callaghan**

Today there are only two nations with the infastructure capable of taking humans to space: China and Russia. The latter has been doing so since 1961, although back then of course it was part of the Soviet Union. This record is a feat unmatched around the world even by the US, but aside from their manned programme the Soviet Union and to a lesser extent Russia have been responsible for some daring endeavours without which our modern missions might not be possible.

The history of Russian rocket theory and application has its roots far back in the late 19th Century. It was the Soviet rocket scientist Konstantin Tsiolkovsky who first postulated a theory of astronautics and he later went on to publish a proposal for a multi-stage rocket in 1929. In the Thirties, meanwhile, an engineer called Sergei Korolev cemented himself at the centre of the Soviet rocket programme. Despite being imprisoned for most of World War Two, Korolev would become one of the most important figures in the Soviet space programme of the Fifties and Sixties.

Following the Allied victory, and despite the requisitioning of most of Nazi Germany's rocket scientists by the US, the Soviet Union managed to obtain drawings of Germany's deadly V-2 rocket. In the early Fifties the USSR built rockets based on the V-2 that were capable of reaching space, known as the R-1 rocket, and in 1951 it launched two dogs into the cosmos, 101 kilometres (63 miles) high.

Mir as seen from Space Shuttle Atlantis above New Zealand during the STS-76 mission on 23 March 1996

By 1957 the R-1 had been upgraded to the R-7 Semyorka intercontinental ballistic missile (ICBM). Although initially intended for militaristic purposes, this rocket would become the cornerstone of the Soviet space programme and indeed Russia's modern rockets, namely the Soyuz-U, would build upon the same design and technology. The four strap-on boosters surrounding its core was a revolutionary design that allowed manned spacecraft to reach orbit.

On 4 October 1957 the Soviet Union stunned the world when it launched the world's first man-made satellite, Sputnik 1, aboard a modified R-7 Semyorka rocket. The launch was a blow to the USA, who had thought it was ahead of the Soviets with its rocket technology, thanks in part to the huge degree of secrecy that the Soviet government insisted upon in its space programme. In fact, many details of the Soviets' space endeavours were not revealed until the early Nineties following the fall of the USSR.

With the success of Sputnik 1, Korolev was tasked with accelerating the manned Soviet space programme. In what was arguably his greatest accomplishment, on 12 April 1961 Yuri Gagarin became the first human to enter space aboard a Vostok spacecraft, a vehicle that at one stage had been intended as a spy satellite.

In his "We choose to go to the Moon" speech in September 1962, President Kennedy made it clear that America's intention was to land humans on the lunar surface. Korolev's plans, however, were wildly more ambitious. He was in the process of designing spacecraft to take humans to Mars as early as 1968, utilising orbiting space stations in the process. It was an infatuation that he largely kept secret from the Soviet government for fear of reprimand, and later he would be forced to shelve his dreams in favour of competing for a lunar landing.

As the Cold War escalated the Soviet space programme was able to enjoy a large amount of funding as the government pumped money into the research and development of missile technology. It's estimated that there were as many as 30 rockets or spacecraft being worked on in the early Sixties, and by the mid-Sixties the Soviets had achieved a huge number of space firsts, including the first probe launched to Venus, the first woman in space, the first spacewalk and the first unmanned lunar landing. In 1966, however, the Soviets would be dealt a huge blow following the death of Korolev.

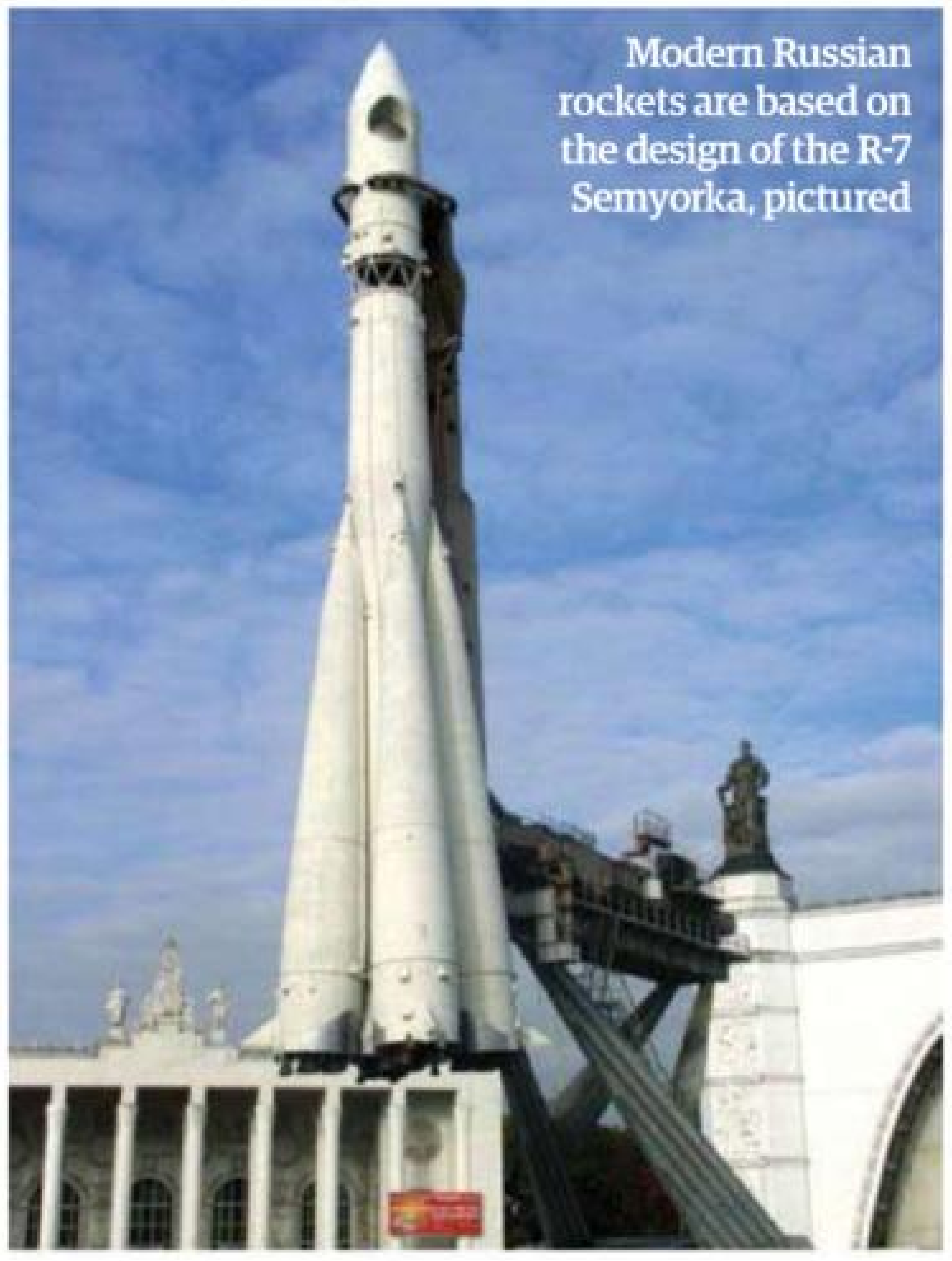
The Soviet space programme was already fraught with internal bickering. Several chief designers were vying for control, despite Korolev's successes, and it wasn't until 1964 that he was given complete control after years of wrangling. In the same year the Soviets would decide to directly challenge the US in landing humans on the Moon, with a somewhat ambitious target of 1967 given to Korolev.

He immediately began to focus efforts on a heavy-lift rocket to rival NASA's Saturn V. The N-1 rocket, whose development actually began in 1959, was meant to be larger and more powerful than anything the Soviets had launched before. With a payload capacity of at least 90,000 kilograms (200,000 pounds), it would have the lifting capacity necessary to take a manned spacecraft and lander to the Moon.

But with progress on the rocket continuing apace, Korolev would die from a combination of heart disease and cancer on 14 January 1966 at the age of 59. His successor would be Soviet engineer Vasily Mishin, who oversaw one of the worst periods in the Soviet space programme. Lacking the authority of his predecessor when dealing with his rivals, Mishin approved the flight of the vastly under-prepared Soyuz 1 spacecraft on 23 April 1967 in a doomed attempt to gain credibility. The mission was a disaster with its sole cosmonaut, Vladimir Komarov, being killed during a botched re-entry.

Things went from bad to worse for Mishin. On 21 February 1969, two months after the US had sent men around the Moon on Apollo 8 and several months before the Apollo 11 mission, the first attempted unmanned launch of the N-1 lunar rocket saw it explode 69 seconds after liftoff. The next three attempted flights, culminating on 23 November 1972, would also end in failure. Coupled with the success of America's lunar programme, the USSR cancelled development of the N-1 rocket and in turn ended its attempts to land men on the Moon.

In fact, prior to this final failed launch, the Soviets had already begun preparations to shift their focus



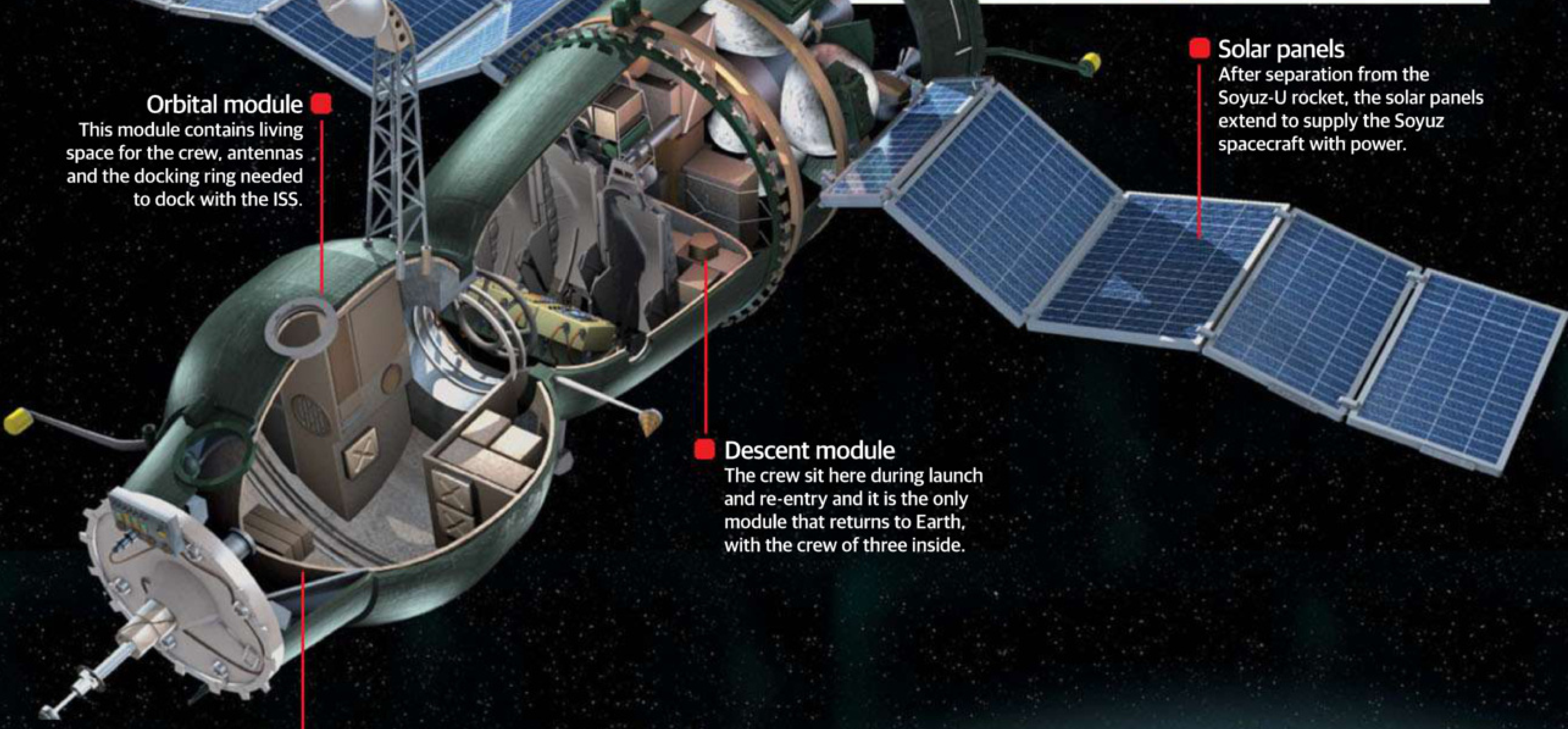
Modern Russian rockets are based on the design of the R-7 Semyorka, pictured

"The first attempted unmanned launch of the N-1 lunar rocket saw it explode 69 seconds after liftoff"

# The Soyuz spacecraft

Inside the world's longest-serving manned space vehicle

The Soyuz is used to ferry astronauts and cosmonauts to and from the ISS



**Service module**
The oxygen, fuel and rocket engines to propel the Soyuz towards the ISS are located here, while radiator panels expel excess heat into space.

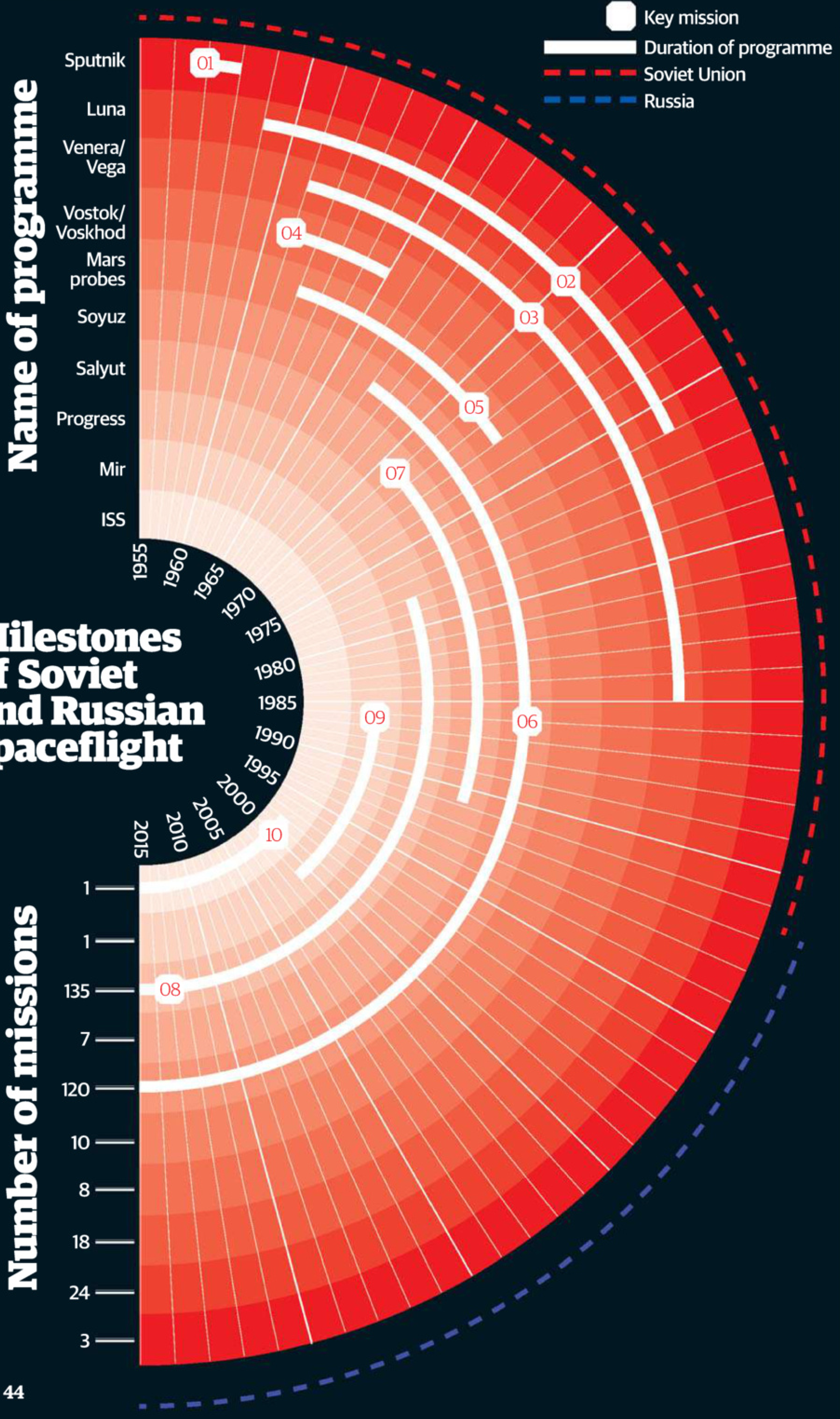
**Orbital module**
This module contains living space for the crew, antennas and the docking ring needed to dock with the ISS.

**Solar panels**
After separation from the Soyuz-U rocket, the solar panels extend to supply the Soyuz spacecraft with power.

**Descent module**
The crew sit here during launch and re-entry and it is the only module that returns to Earth, with the crew of three inside.

**Dimensions**
The modern Soyuz TMA-M is 7.48m (24.5ft) long, 2.72m (8.9ft) in diameter and weighs 7,150kg (15,760lb).

# Milestones of Soviet and Russian spaceflight



## Key missions

**1. Sputnik 1**
**4 October 1957**
Completing over 1,400 orbits of Earth in 90 days, Sputnik 1 was the world's first man-made satellite.

**2. Lunokhod 1**
**10 November 1970**
Luna 17 was the 17th of the Luna Moon probes and carried with it Lunokhod 1, the first rover to operate on the Moon.

**3. Venera 7**
**15 December 1970**
This Soviet probe was the first spacecraft to successfully land on another planet and return data.

**4. Vostok 1**
**12 April 1961**
Yuri Gagarin became the first human in space on 12 April 1961 aboard Vostok 1.

**5. Mars 3**
**28 May 1971**
A lander released by the Mars 3 orbiter performed the first successful landing on the Red Planet.

**6. Soyuz T-15**
**13 March 1986**
The first, and to date only, spacecraft to visit two space stations (Mir and Salyut 7) in the same mission was Soyuz T-15 with its two-man crew.

**7. Salyut 1**
**19 April 1971**
The world's first space station was Salyut 1, launched on 19 April 1971. It was followed by six more including Salyut 7 in 1991.

**8. Progress**
**25 November 2013**
Three to four Progress vehicles dock with the ISS every year, including most recently on 25 November 2013.

**9. Mir**
**20 February 1986**
Launched on 20 February 1986, Mir was a huge success for the Soviet Union and later Russia.

**10. Expedition 1**
**31 October 2000**
On 31 October 2000 a Soyuz spacecraft took the first long-duration crew to the ISS.

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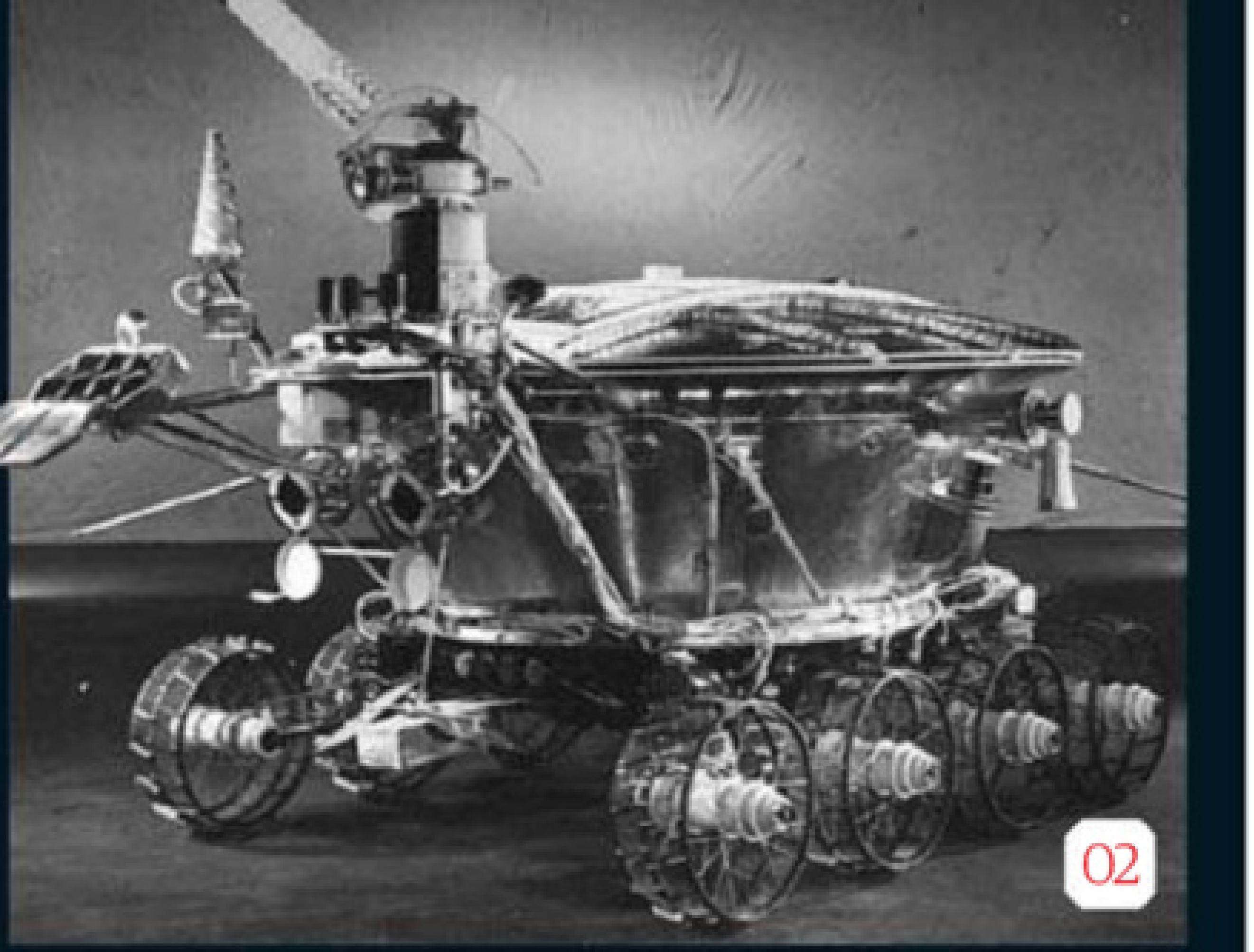
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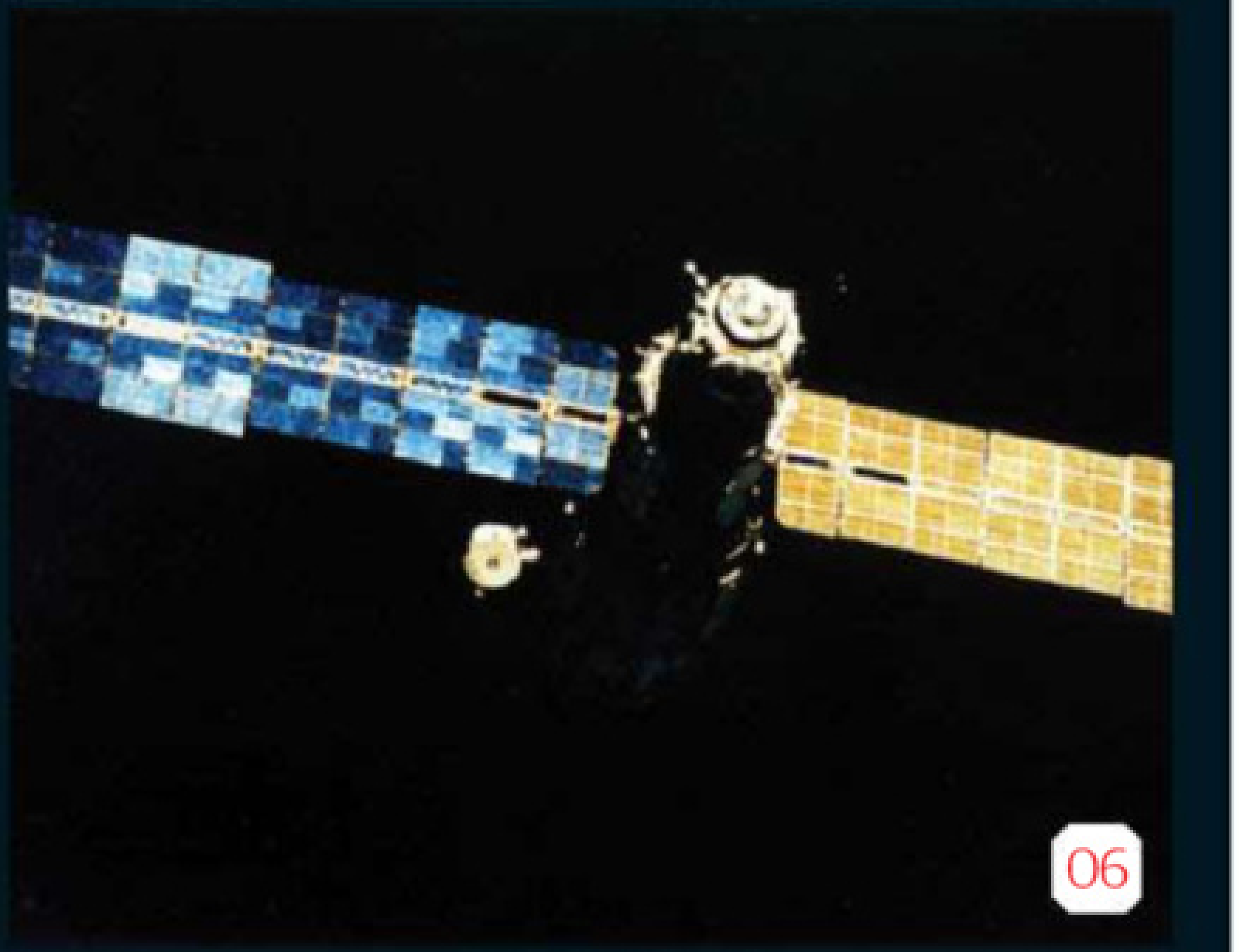
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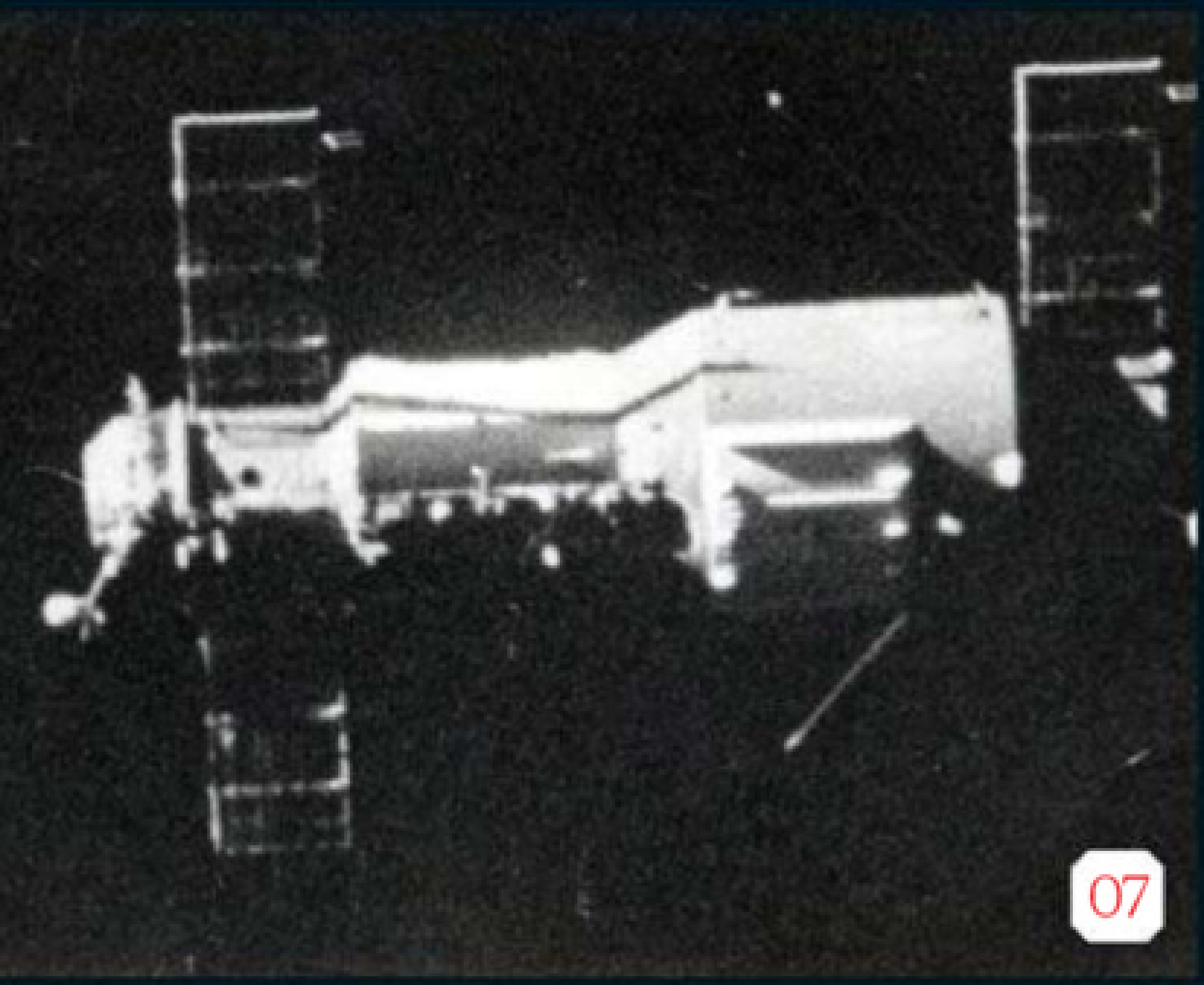
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to developing, building and operating a series of space stations in Earth orbit and, in doing so, pre-empt NASA's Skylab space station. The first of these was Salyut 1 in 1971, which would itself experience a devastating failure; during re-entry a ventilation valve opened and their Soyuz spacecraft depressurised. This tragically killed all three crew members since at the time, they did not wear their space suits while in flight. Following the fatal incident, all cosmonauts were required to wear pressure suits on launch and re-entry.

But Salyut 1 was merely the first in a series of mostly successful space stations in the Salyut programme as the Soviets endeavoured to perfect manned occupation of Earth orbit. Mishin was removed from his post following the Salyut 1 disaster and his successor, Vladimir Chelomei, achieved a great many successes with the Salyut programme. In the same decade the Soviet space programme added to its burgeoning list of accomplishments, including the Venera series of unmanned spacecraft that landed on and orbited Venus numerous times. And, in 1975, we saw a groundbreaking moment in the relationship between the US and USSR when an Apollo and a Soyuz spacecraft were docked in Earth orbit in the Apollo-Soyuz Test Project (ASTP), heralding a new era of exploration that favoured cooperation over competition.

The missions we've highlighted so far were just a portion of the extent of the Soviets' space endeavours, though. Even into the Eighties there were numerous spacecraft in development including the Buran spacecraft, an almost like-for-like replica of NASA's Space Shuttle that was cancelled in 1993. In 1986 the Soviet Union would undertake its most ambitious mission yet. As far back as 1976 it had begun research into a space station that would far exceed any of the Salyut stations in size. It would also be a so-called 'third generation' station. The 'first generation' was regarded as those that launched as a whole, so no in-orbit assembly was possible, and they had no means of resupply. 'Second generation' referred to single-stage stations that had an extra docking port for resupply spacecraft. This 'third generation', meanwhile, comprised a station that could be assembled and modified in orbit. This meant the core module – the living quarters – could be launched first, and then subsequent specialist modules could be launched and attached.

On 19 February 1986 the first component of the station, which would be called Mir, was launched on a Proton-K rocket. This would be followed by six more modules leading up to the station's completion on 26 April 1996, including most notably a docking module that was brought to the station by NASA's Space Shuttle Atlantis STS-74 mission on 15 November 1995. Mir enabled long-term habitation of space by a crew of three for the first time and, in the

> "Mir enabled long-term habitation of space by a three-man crew"

Storemags

Soyuz rockets are assembled in a processing hangar at the Baikonur Cosmodrome in Kazakhstan before being rolled out to the launch pad

process, the record for the longest stay in space was set aboard Mir and remains intact to this day: 437 days and 18 hours from January 1994 to March 1995, set by cosmonaut Valeri Polyakov.

The launch and operation of Mir coincided with an eventful period in history: the dissolution of the USSR on 26 December 1991. With the separation of Russia from the Soviet Union, the Russian Federal Space Agency was formed on 25 February 1992 as a central agency to unify the various bureaus that had made up the previous Soviet space programme.

More commonly known as Roscosmos, the agency was now given significantly less funding than during the Cold War. With so many different projects and spacecraft still being researched and developed, Roscosmos was forced to streamline its operations in an attempt to balance its books. Therefore, in the Nineties, the agency would focus on commercial launches and manned exploration, with the latter taking up about half of its budget, a much larger proportion than at other global space agencies.

To raise money, Roscosmos began launching numerous commercial satellites on its Progress rockets and also started making plans to sell seats on its manned Soyuz spacecraft through its space tourism programme. Meanwhile, in 1993 it entered into a partnership with NASA to build the International Space Station, a global endeavour that would surpass Mir in almost every way. Mir, however, had provided national space agencies with a wealth of data that would prove invaluable in constructing and operating the ISS. With focus now shifting to the ISS, and with its first module (Russia's Zarya) launched on 20 November 1998, the decision was made to de-orbit Mir on 23 March 2001, ending its stay of more than 15 years in space.

"Roscosmos has a number of new projects in operation or development"

By the turn of the century, Russia had cemented itself as the leading player in manned launches to Earth orbit. Its Soyuz vehicles, modified variants of the same spacecraft that had been in operation since that first disastrous flight in 1966, were now the world's safest and most reliable means of taking humans into space. Indeed, with the Space Shuttle now retired they are the only means of taking humans to space aside from China's Shenzhou spacecraft, until new spacecraft from NASA and private space agencies come into operation. Its unmanned Progress vehicle is also one of the primary methods of taking cargo to the ISS.

Today its rockets launch from the Baikonur Cosmodrome in Kazakhstan, the same launch complex used by the Soviets in the Fifties. It is the world's first and largest launch facility, and is responsible for about half a dozen launches of the Soyuz and Progress spacecraft every year. In addition to these programmes, the funding for Roscosmos is steadily increasing and a number of new projects are in operation or development. This includes the Mars 500 simulation, a project in partnership with ESA and China that served to study the psychological effects of long-term isolation for a future Mars mission that was completed in 2011, a return to Venus with the Venera D probe by 2024, an upgraded six-person Soyuz spacecraft and a return to the Moon with its Luna-Glob programme beginning in 2016.

Just as the Soviet space programme began, with a focus on manned exploration, so Roscosmos has come full circle with its modern accomplishments. Its plans for more ambitious missions in the coming years will once again allow Russia to perform the same sort of groundbreaking science of other agencies around the world. Roscosmos has overcome troubling times to cement its position at the forefront of manned space exploration and a new era of scientific exploration is dawning that will take the agency in a revolutionary direction. ■

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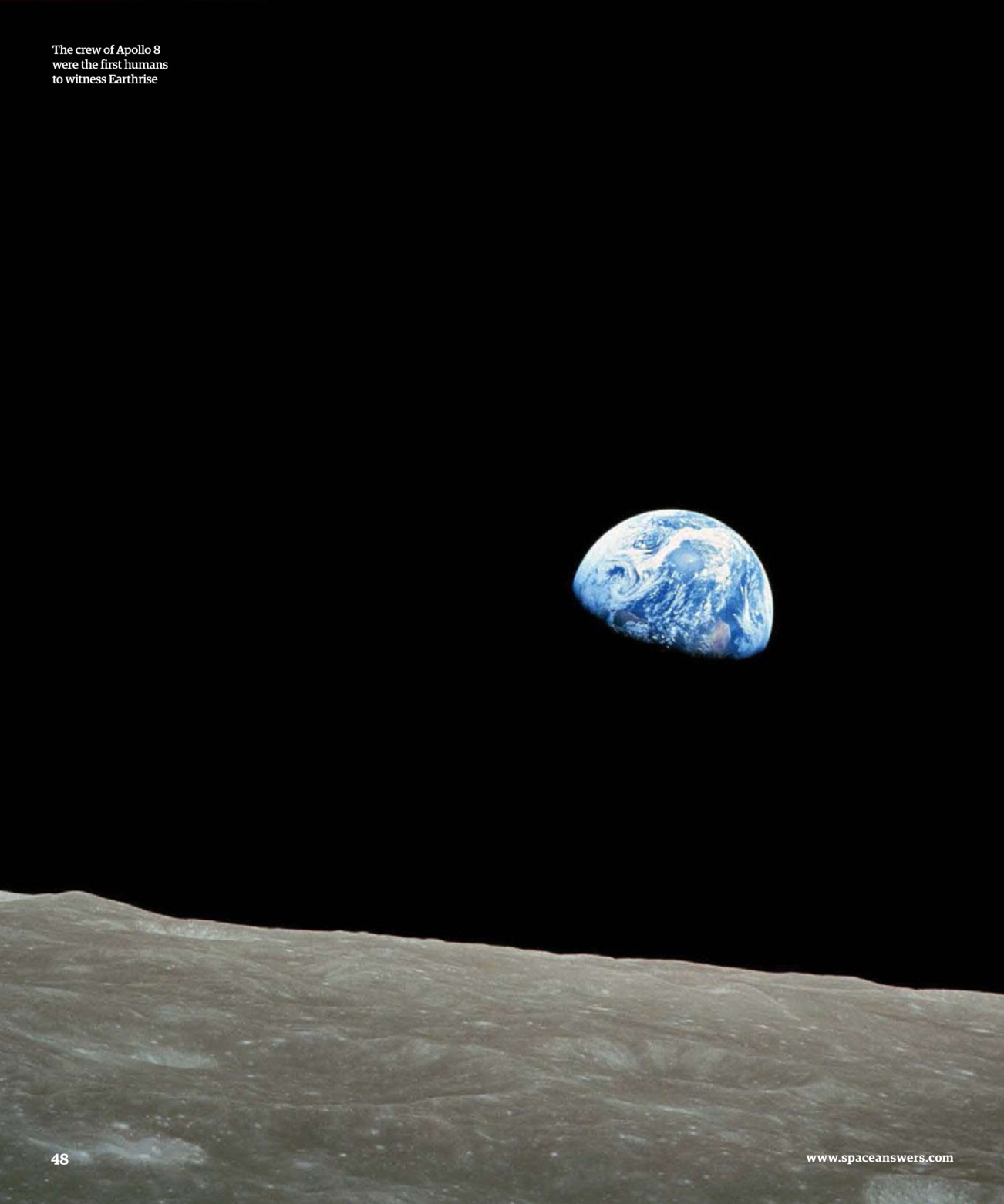


The crew of Apollo 8 were the first humans to witness Earthrise

# Earthrise

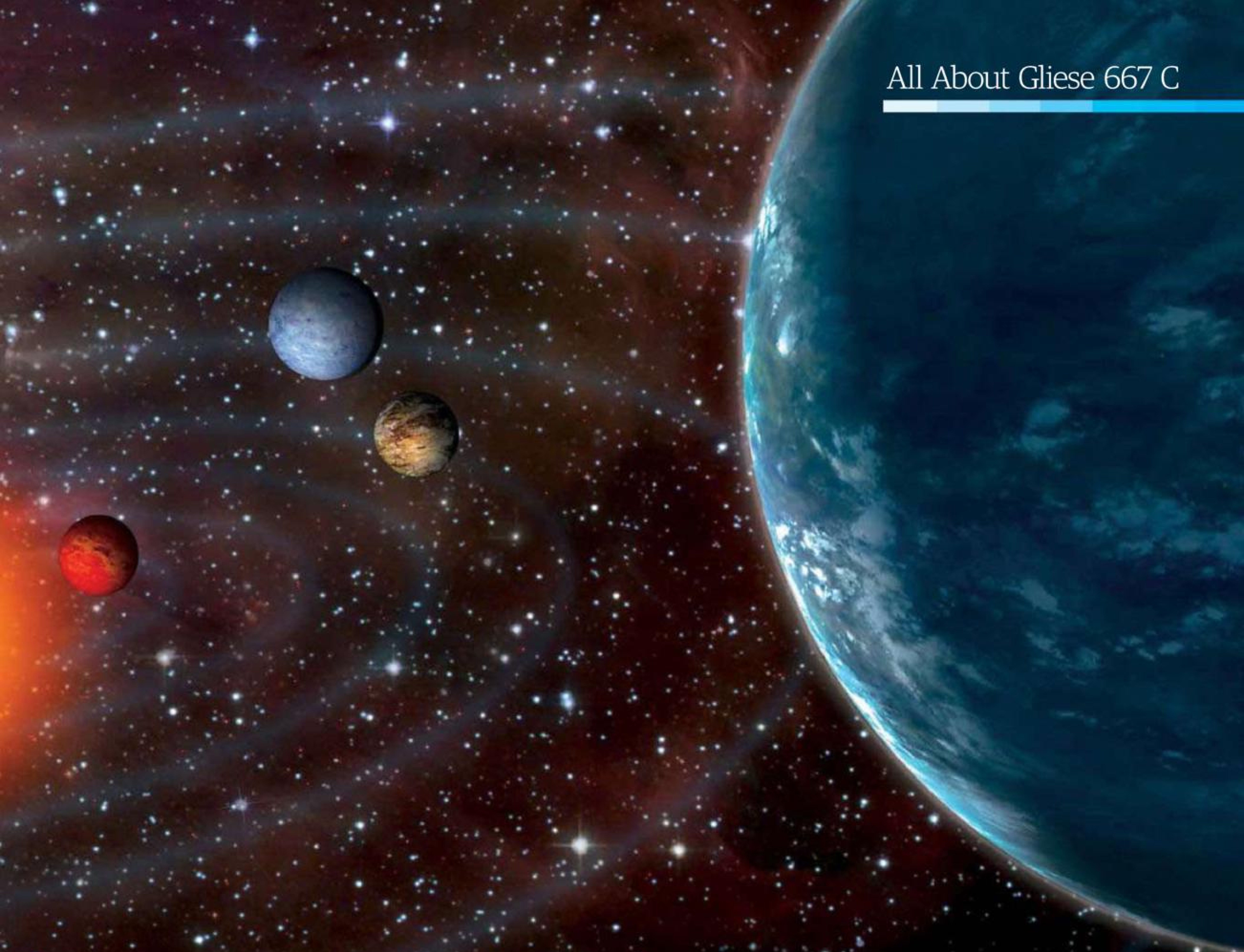
## 45 years ago, on 24 December 1968, the crew of Apollo 8 became the first humans to orbit the Moon

"Oh my God! Look at that picture over there! Here's the Earth coming up. Wow, is that pretty." Those were the words of Commander Frank Borman when he, along with Command Module pilot James Lovell and Lunar Module pilot William Anders, observed the Earth rising as they made their way around lunar orbit. They were the first humans to witness the event, known as 'Earthrise', and in doing so captured the first such images of Earth from afar.

This particular photo was taken by Anders on 24 December 1968, with some later calling it one of the most influential photographs of all time. It shows the fragility of our world from the distance of the Moon, 380,000 kilometres (235,000 miles) away.

Apollo 8 was an important milestone in the Apollo programme, as it tested some of the key technologies and manoeuvres that would be employed by the later missions that landed on the lunar surface. Having launched on 21 December 1968 the crew returned to Earth six days later on 27 December, paving the way for Neil Armstrong and Buzz Aldrin's historic first steps in July 1969.

© NASA



# All About...

# OUR TWIN SOLAR SYSTEM

Part of a triple-star system not far from our own, Gliese 667 C holds the record for having three potentially habitable planets in its orbit

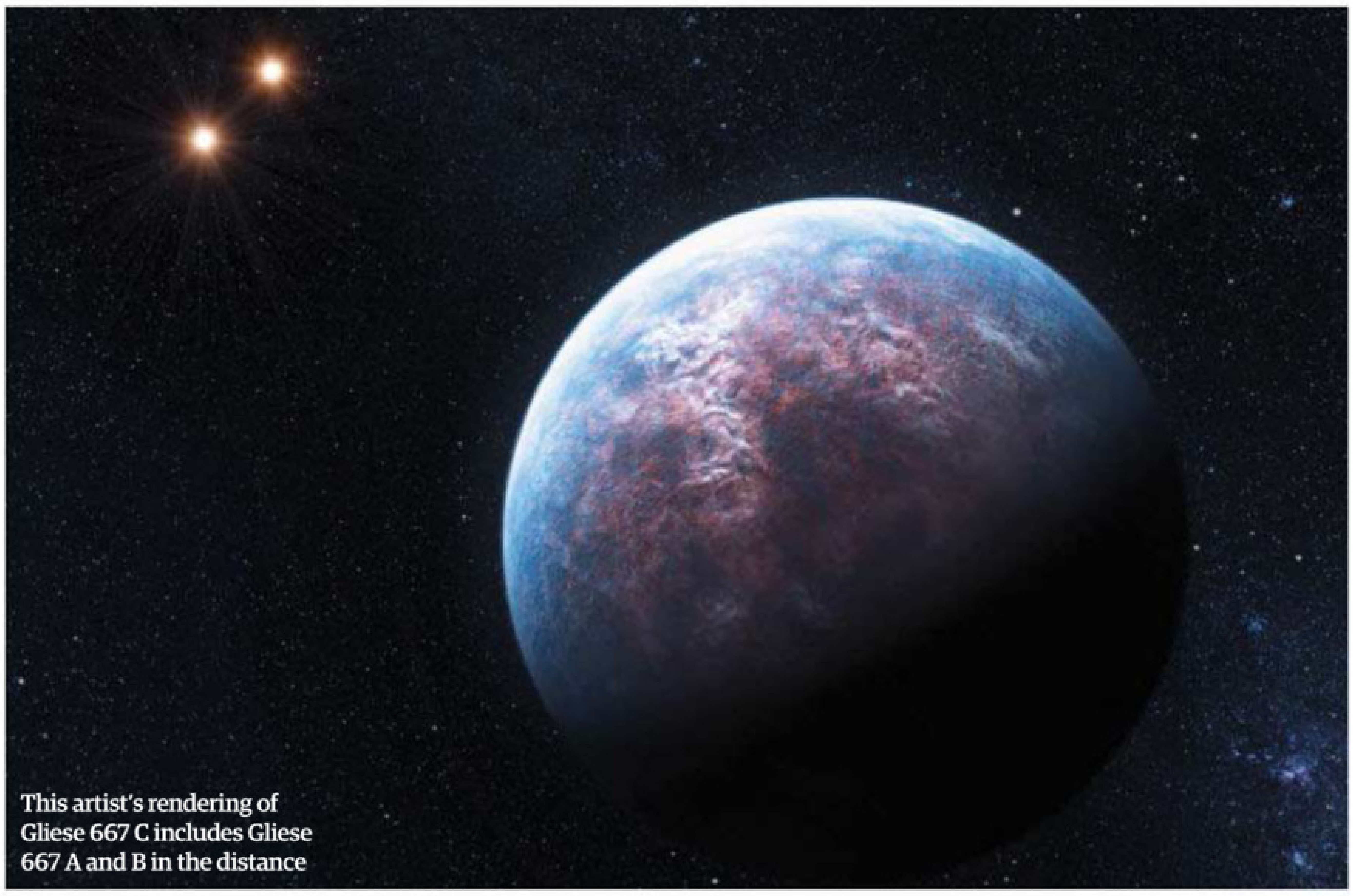
Written by Shanna Freeman

Gliese 667 is located about 22 light years from Earth, and appears to be a single star of about magnitude 5.89 if viewed with the naked eye. Any star above a 6 is considered to be too faint to view without a telescope, so this is a pretty faint star. In reality, Gliese 667 is a triple-star system - a system in which three stars are gravitationally bound to each other - located in the Scorpius constellation. Each of the three stars in the system are much smaller than the Sun.

The three stars are named Gliese 667 A, B and C. Gliese 667 A and B are the brightest two stars in the system. Gliese 667 A is a K-type main-sequence star, also called an orange dwarf or K dwarf. The K designation means that it is a relatively cool star, between 3,627 to 4,927 degrees Celsius (6,561 to 8,900 degrees Fahrenheit) on the surface. These stars have masses between 60 and 90 per cent that of the Sun's mass, and stay on the main sequence for longer than the Sun does - 15 to 30 billion years, as opposed to the Sun's ten billion years. Orange dwarfs are up to four times more common than Sun-like stars, and tend to have mostly neutral metals like silicon, iron and manganese in addition to helium and hydrogen. Gliese 667 A radiates about 12 per cent of the Sun's luminosity, but has about 75 per cent of its mass. Gliese 667 B is the secondary star in the system and also an orange dwarf, but it's slightly smaller than A and is a little further along in the main-star sequence. It has a mass about 69 per cent that of the Sun and radiates about five per cent of the Sun's luminosity. Gliese 667 B is also brighter than A. These two stars orbit each other, with an eccentricity of about 0.6. This means that the distance between them varies from 5 AU (astronomical units, or Earth to Sun distances) to 20 AU. It takes about 42 years to complete one orbit.

Because of the long period of time they spend on the main sequence, orange dwarfs present a good opportunity for astronomers to search for extraterrestrial planets. Therefore, it's interesting that the third star in the system - Gliese 667 C - is the one in the system known to have planets in orbit around it. It's an M-class star, specifically a red dwarf. While on the main sequence, these stars are smaller and cooler than orange dwarfs. Their masses can be up to 50 per cent of the Sun and, temperature-wise, red dwarfs are less than 3,727 degrees Celsius (6,741 degrees Fahrenheit) on the surface. Red dwarfs are the most common type of star in the galaxy. Gliese 667 C is believed to have about 30 per cent of the Sun's mass and 42 per cent of the Sun's radius, and is relatively inactive. That makes it ideal for investigating orbiting planets. While Gliese 667 A and B are so close together that they're often grouped on maps as Gliese 667 AB, Gliese 667 C orbits the other two stars at a much further distance. There's a minimum of 230 AU between Gliese 667 AB and Gliese 667 C. We believe that it has at least five, and as many as seven, planets orbiting it. Three of the planets have been dubbed super-Earths and may be habitable. ■

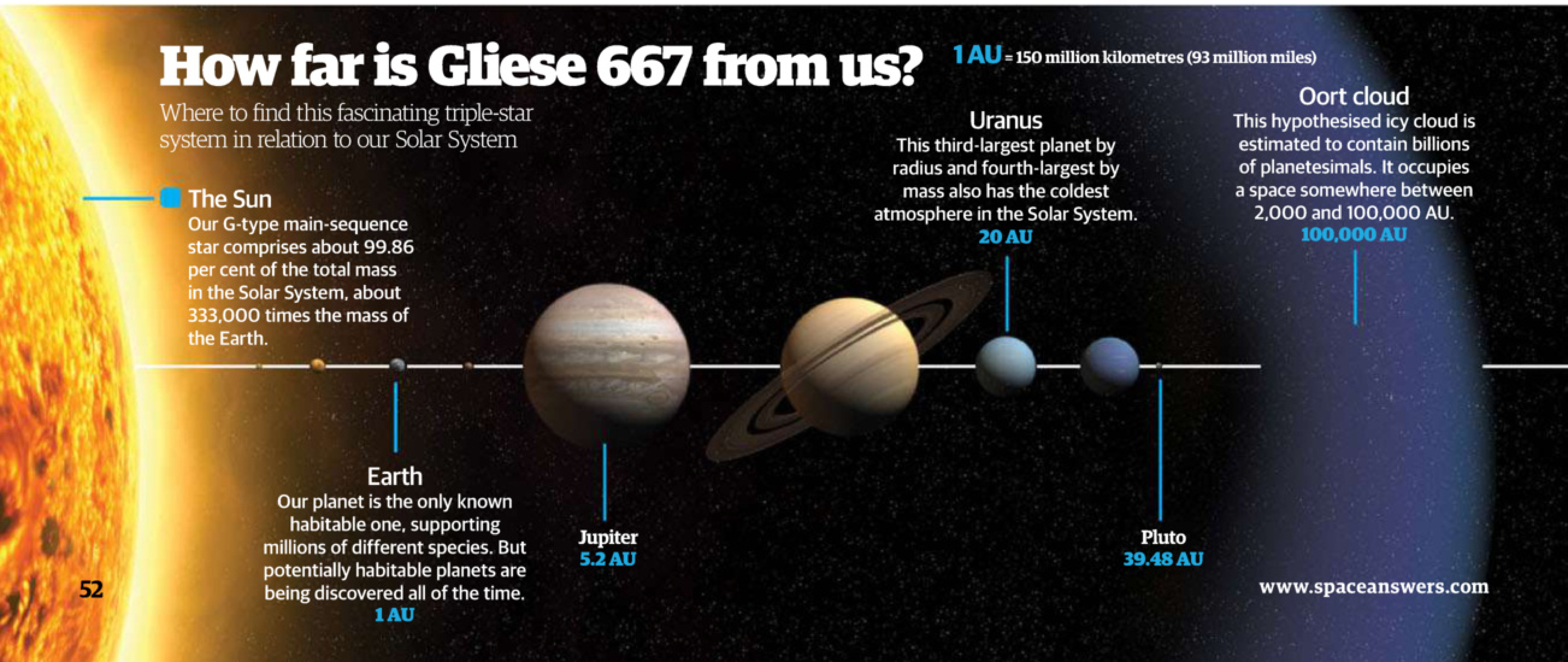
> "It's believed to have at least five, and as many as seven, planets orbiting it"



This artist's rendering of Gliese 667 C includes Gliese 667 A and B in the distance

## How far is Gliese 667 from us?

Where to find this fascinating triple-star system in relation to our Solar System



**1 AU** = 150 million kilometres (93 million miles)

**The Sun**
Our G-type main-sequence star comprises about 99.86 per cent of the total mass in the Solar System, about 333,000 times the mass of the Earth.

**Earth**
Our planet is the only known habitable one, supporting millions of different species. But potentially habitable planets are being discovered all of the time.
**1 AU**

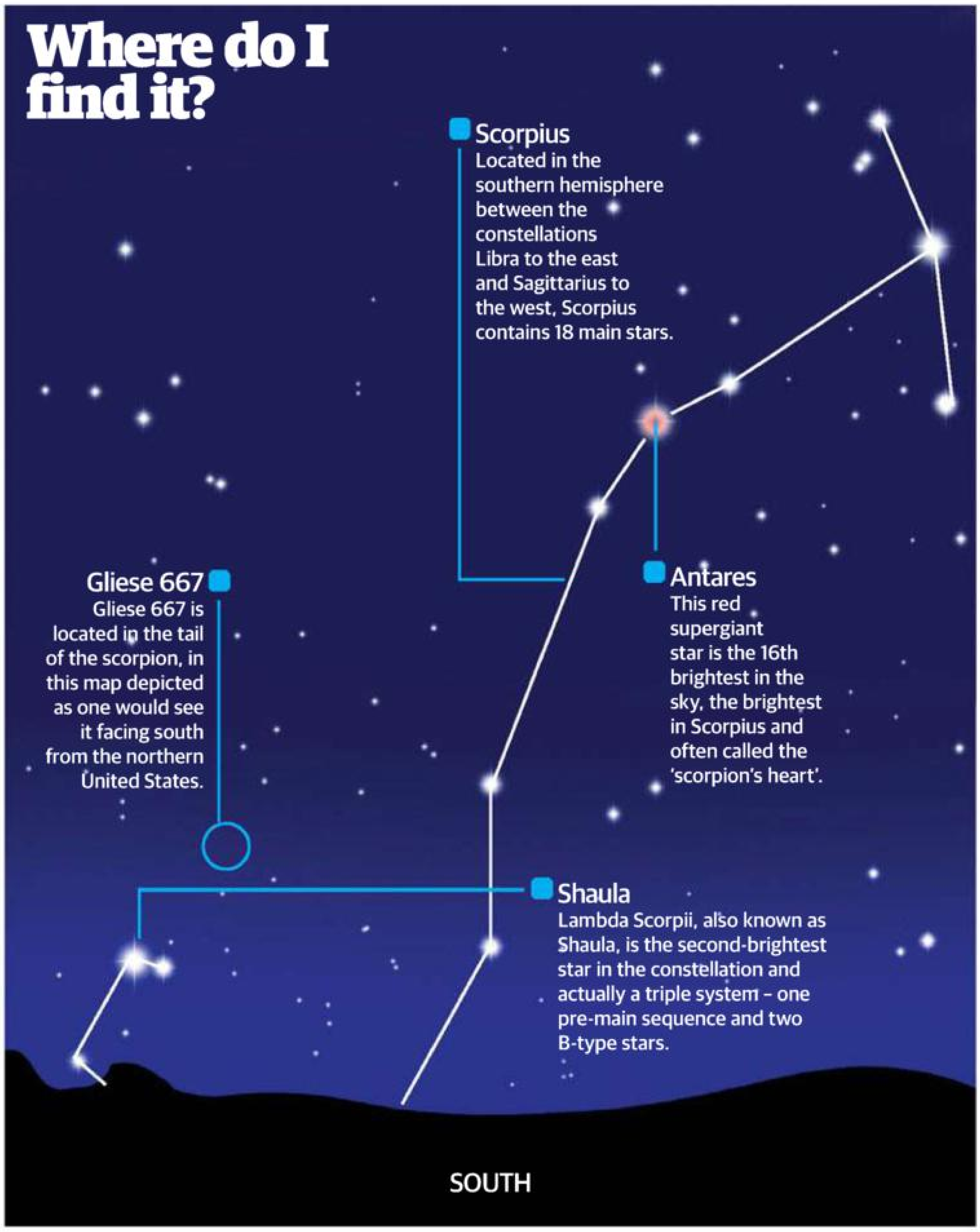
**Jupiter**
**5.2 AU**

**Uranus**
This third-largest planet by radius and fourth-largest by mass also has the coldest atmosphere in the Solar System.
**20 AU**

**Pluto**
**39.48 AU**

**Oort cloud**
This hypothesised icy cloud is estimated to contain billions of planetesimals. It occupies a space somewhere between 2,000 and 100,000 AU.
**100,000 AU**

## Where do I find it?



**Scorpius**
Located in the southern hemisphere between the constellations Libra to the east and Sagittarius to the west, Scorpius contains 18 main stars.

**Gliese 667**
Gliese 667 is located in the tail of the scorpion, in this map depicted as one would see it facing south from the northern United States.

**Antares**
This red supergiant star is the 16th brightest in the sky, the brightest in Scorpius and often called the 'scorpion's heart'.

**Shaula**
Lambda Scorpii, also known as Shaula, is the second-brightest star in the constellation and actually a triple system – one pre-main sequence and two B-type stars.

## By the numbers

**105** days

Gliese 667 C completes one rotation every 105 days

**6±4 billion years**

*Gliese 667 C is estimated to be 6±4 billion years old compared to the Sun's 4.57 billion years*

**1/3**

Gliese 667 C has about one-third of the Sun's mass

**5**

Gliese 667 C has five confirmed planets in its orbit

**85%**

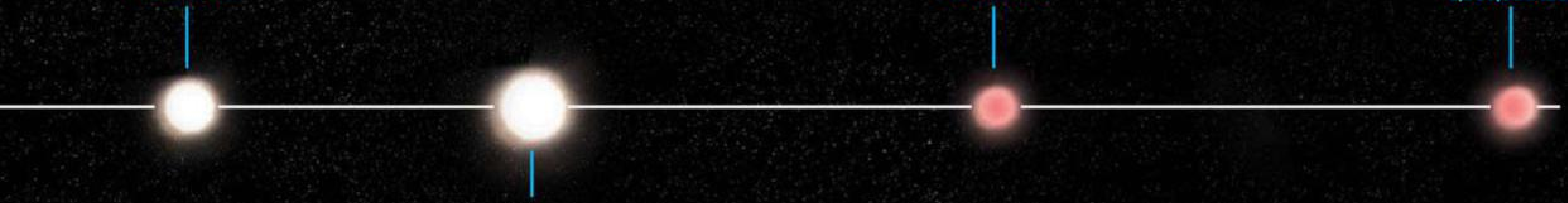
*The planet Gliese 667 Cc is believed to be 85 % similar to Earth*

**6.5km/s**

Gliese 667 C is estimated to rotate at this speed

**1.4%**

Gliese 667 C has just 1.4% of the Sun's luminosity



**Alpha Centauri**
This star is the third-brightest in the night sky and one of the closest stars (actually a binary star system) to our Solar System.
**276,358 AU**

**Sirius**
Called the 'dog star' for its position in Canis Major, Sirius is the brightest star in our night sky.
**543, 862 AU**

**Gliese 876**
This red dwarf is located in the constellation of Aquarius and was found to have at least four planets in orbit around it.
**967,568AU**

**Gliese 667**
Gliese 667 has a high degree of proper motion (nearly 1 arcsecond per year), meaning that it appears to be moving fairly quickly relative to our Solar System.
**1,397,598 AU**

# The planets around star C

## With up to seven planets orbiting it, could we one day discover life in this triple-star system?

As if having the stars Gliese 667 A, B and C wasn't confusing enough, the planets that have been discovered around Gliese 667 C also have alphabetical designations in lower case: b, c, d, e, f, g and h. Two of the planets, Gliese 667 Cg and Gliese 667 Ch, are currently unconfirmed. Three of the five confirmed planets - c, e and f - are considered super-Earths. A super-Earth is generally defined as a planet that is larger than Earth, but generally no larger than ten Earth masses, and also possesses a solid surface. Although the existence of extrasolar planets in general is rather exciting, finding ones that may be habitable - according to our Earth standards - captures even more interest.

The habitable zone - also known as the 'Goldilocks zone' - of a star is an area around the star where the temperature is 'just right'. It's neither too hot nor too cold, but has the right conditions to support a planet with an Earth-like atmosphere and liquid water. If the planet is too close to the star, then any liquid water would boil away, but being too far would mean that most of the water would be in the form of ice. The current parameters for Gliese 667 C's habitable zone extends from an inside boundary between 0.095 and 0.126 AU to an outside boundary of 0.241 and 0.251 AU. This range is roughly equivalent to the orbit of Mercury, so planets within it are much closer to the star than the Earth is to the Sun. However, since a red dwarf is a smaller, cooler and dimmer star than the Sun, planets in this small region can still be habitable.

> "Gliese 667 Cc is the most Earth-like of the planets"

The first planet discovered around Gliese 667 C was Gliese 667 Cb in 2009. It is the most massive of the planets and is considered to be either a super-Earth or a mini-Neptune. The latter is also sometimes called a transitional planet or a gas dwarf; these are believed to have thick atmospheres of hydrogen and helium, with small cores surrounded by layers of ice, liquid oceans or rock. Gliese 667 Cb orbits too close to the star for the planet to be in the habitable zone. Next came Gliese 667 Cc, first mentioned in 2011 and officially announced a year later. Its mass is between 4.5 and 9 Earth masses, and it is believed to be a rocky planet located along the inner edge of the habitable zone at about 0.1251 AU. Gliese 667 Cc is estimated to have an orbital period of about 28 days, and it would get about 90 per cent of the radiation that the Earth gets from the Sun. However, most of it would be absorbed, making the planet warmer overall than the Earth, but still potentially habitable, at approximately 30 degrees Celsius (86 degrees Fahrenheit). Gliese 667 Cc is the most Earth-like of the planets found around Gliese 667 C.

Gliese 667 Cd was discovered in 2012, and its existence was confirmed in 2013. It is slightly more massive than Gliese 667 Cc, but it's probably an icy planet because it's outside of the habitable zone while orbiting at about 0.2758 AU. Gliese 667 Cd may have a liquid water layer under its ice, however. Discovered in 2013, Gliese 667 Ce is located in the habitable zone - orbiting at a distance of 0.21257 AU - and is believed to be slightly less massive than Gliese 667 Cc. Gliese 667 Cf was also discovered in 2013, but it's directly in the middle of the habitable zone at around 0.15575 AU. Like Gliese 667 Cf, it is also a little less massive than Gliese 667 Cc.

There are also the unconfirmed planets, known as Gliese 667 Cg and 667 Ch. Both were predicted to exist prior to being announced in mid-2013. Gliese 667 Cg likely lies outside of the habitable zone and is an icy planet, with a mass somewhere between 4.41 and 9 Earth masses. Gliese 667 Ch is probably much smaller, between 1 and 2 Earth masses, and is projected to be located just outside the habitable zone - probably too close to the star. There is little evidence of the existence of Gliese 667 Ch so far. It's unlikely that there are more planets in the habitable zone of Gliese 667 C, because there are no more stable orbits available in that region. ■

## The habitable worlds

**Gliese 667 Cc**

Of the three potentially habitable planets around Gliese 667 C, Cc is considered the most Earth-like. It's much bigger than the Earth - at least 4.5 times its mass - but it's believed to be similar in composition, in temperature and the amount of light received from its star.

**Gliese 667 Cf**

This planet is smaller than Cc and is thought to be just under two Earth masses. It's in the middle of the habitable zone and should get about 60% of the starlight that the Earth receives from the Sun. But it's also thought to absorb more infrared light than the Earth and is slightly warmer.

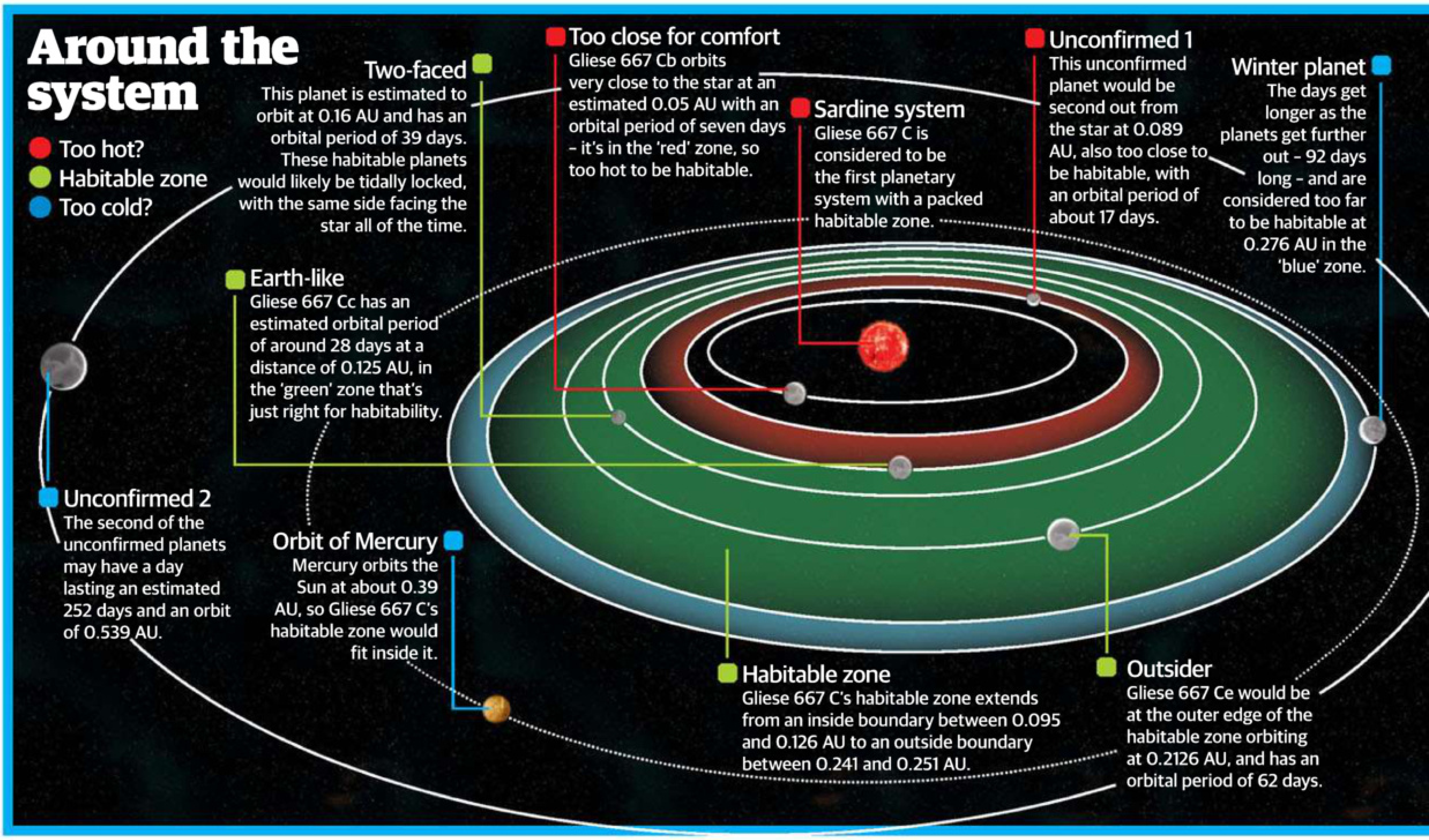
**Gliese 667 Ce**

Also smaller than Cc, Ce has an estimated mass somewhere between 2.5 and 3 Earth masses. Although it probably gets only a third of the starlight that the Earth gets from the Sun, if there are greenhouse gases present in its atmosphere it can still have liquid water.

**Earth**

It's difficult to envision that the three potential super-Earths around Gliese 667 C could have much in common with our Earth. It's important to remember that despite the designation of habitable zone, the concept of alien life existing on these planets is theoretical.

## Around the system



🔴 Too hot?
🟢 Habitable zone
🔵 Too cold?

**Two-faced**
This planet is estimated to orbit at 0.16 AU and has an orbital period of 39 days. These habitable planets would likely be tidally locked, with the same side facing the star all of the time.

**Too close for comfort**
Gliese 667 Cb orbits very close to the star at an estimated 0.05 AU with an orbital period of seven days – it's in the 'red' zone, so too hot to be habitable.

**Sardine system**
Gliese 667 C is considered to be the first planetary system with a packed habitable zone.

**Unconfirmed 1**
This unconfirmed planet would be second out from the star at 0.089 AU, also too close to be habitable, with an orbital period of about 17 days.

**Winter planet**
The days get longer as the planets get further out – 92 days long – and are considered too far to be habitable at 0.276 AU in the 'blue' zone.

**Earth-like**
Gliese 667 Cc has an estimated orbital period of around 28 days at a distance of 0.125 AU, in the 'green' zone that's just right for habitability.

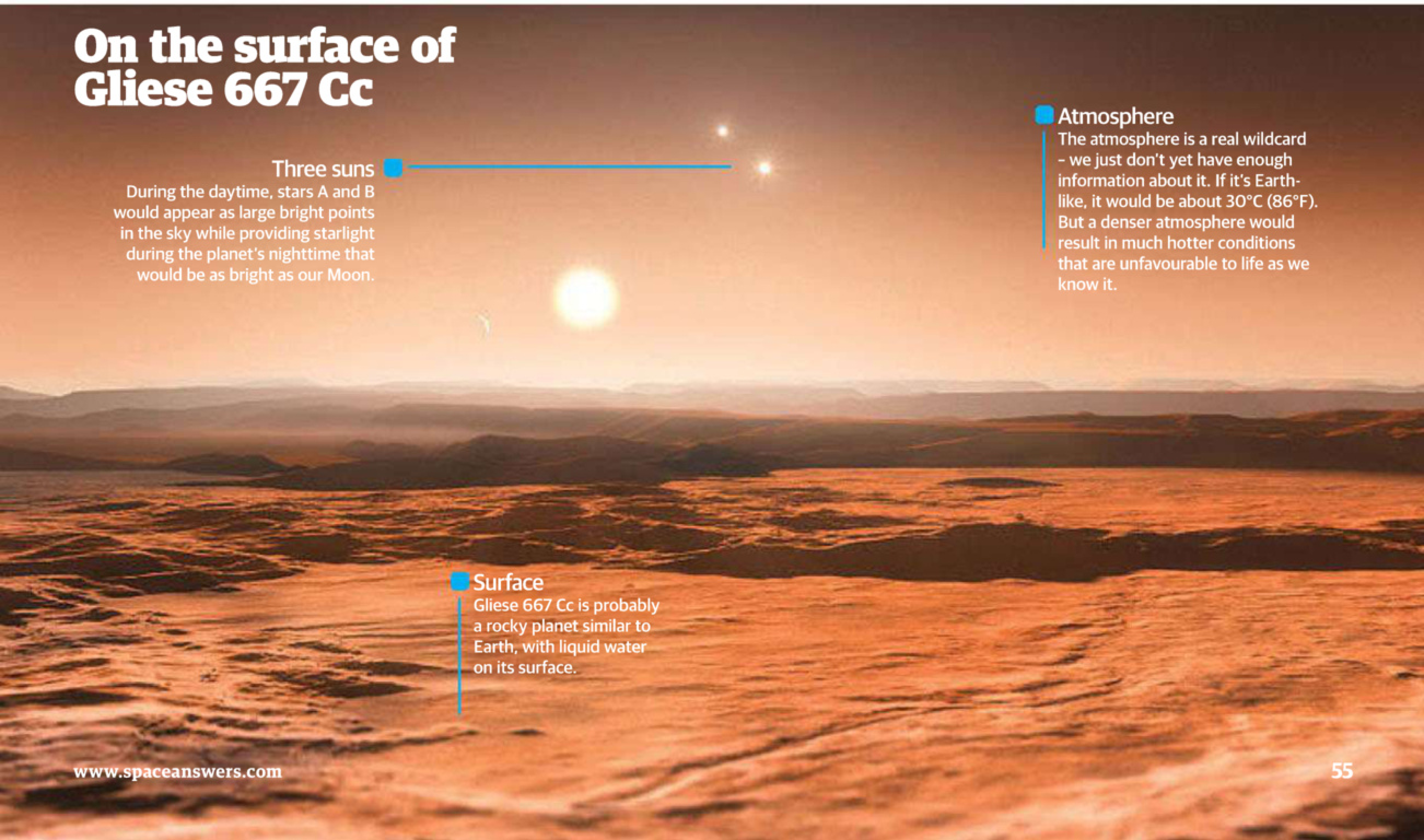
**Unconfirmed 2**
The second of the unconfirmed planets may have a day lasting an estimated 252 days and an orbit of 0.539 AU.

**Orbit of Mercury**
Mercury orbits the Sun at about 0.39 AU, so Gliese 667 C's habitable zone would fit inside it.

**Habitable zone**
Gliese 667 C's habitable zone extends from an inside boundary between 0.095 and 0.126 AU to an outside boundary between 0.241 and 0.251 AU.

**Outsider**
Gliese 667 Ce would be at the outer edge of the habitable zone orbiting at 0.2126 AU, and has an orbital period of 62 days.

## On the surface of Gliese 667 Cc



**Three suns**
During the daytime, stars A and B would appear as large bright points in the sky while providing starlight during the planet's nighttime that would be as bright as our Moon.

**Atmosphere**
The atmosphere is a real wildcard – we just don't yet have enough information about it. If it's Earth-like, it would be about 30°C (86°F). But a denser atmosphere would result in much hotter conditions that are unfavourable to life as we know it.

**Surface**
Gliese 667 Cc is probably a rocky planet similar to Earth, with liquid water on its surface.

# Observing our neighbour

## Exoplanet hunter HARPS is one of many instruments searching out fascinating new planetary systems

The star system Gliese 667 has been observed as a single faint star from Earth, with advances in telescope technology allowing us to differentiate between the three stars in the system. However, the planetary system around Gliese 667 C could not have been discovered without the European Southern Observatory's HARPS instrument, or High Accuracy Radial velocity Planet Searcher.

This instrument is a high-precision echelle spectrograph, which uses diffraction gratings – structures that split and diffract light into different beams – to separate incoming waves of light into a very fine frequency spectrum. HARPS uses a method called radial velocity, or wobble, to detect planets. The radial velocity is the velocity of a star or other object in the direction of our line of sight. While a planet orbits a star, the star orbits around its own centre of mass. This interaction causes the star to wobble slightly, producing Doppler shifts in the light it emits. These signals are then detected by HARPS, and they are analysed using a method known as Bayesian statistical analysis to make predictions about the potential planet's mass, orbital periods and size of orbit.

HARPS was installed on the European Southern Observatory's 3.6-metre telescope in 2002, located at the La Silla Observatory in Chile. It sits in a vacuum-sealed, temperature-controlled vessel to avoid any perturbances caused by variations in temperature or air pressure. Two identical optic fibres feed into HARPS. It is one of the most accurate and precise instruments of its kind. It has been used to discover more than 130 planets and since 2012 it has been used to detect habitable super-Earths. These days, it's considered an exoplanet super hunter due to the huge number of exoplanets it has discovered to date.

When HARPS discovered Gliese 667 Cb in 2009, within a few years enough data had been collected about the system to indicate the existence of what scientists called a 'four-planet solution' – b, c, d (unconfirmed at the time), and an unknown 'trend', with a projected long orbital period that couldn't yet be determined. This system could not be considered stable, however, and was revised to a five-planet solution in 2012 with b and c confirmed and three unconfirmed planets: d, e and f. The team believed previously that the star might be host to one potentially habitable planet. Combining the latest observations with data from other sources led the HARPS team to propose a potential seven-planet solution in mid-2013. This includes five strong signals for the planets b, c, f, e and d and the weaker signals for unconfirmed planets h and g. They also came to the conclusion that three of the planets lie in Gliese 667 C's habitable zone – an unprecedented find.

HARPS does have its limitations, however; it can only detect planets orbiting low-mass stars like Gliese 667 C. These stars are more strongly affected by the planets around them, and because their habitable zones tend to be close to the star, planets are easier to detect.

## Future missions

HARPS gets the most attention for its exoplanet discoveries, but there are other instruments on the hunt for planetary systems with habitable planets. Also operated by the European Space Observatory, the Very Large Telescope – actually four telescopes – has also collected data about Gliese 667 C and is considered the most productive telescope on the ground right now. The Magellan Telescopes at Las Campanas Observatory in Chile have a Planet Search Program, and the WM Keck Observatory in Hawaii has also contributed invaluable data to the study of Gliese 667 C. There are more tools on the horizon, too. The European Space Observatory plans to install the ESPRESSO (Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations) instrument on its Very Large Telescope and have it begin receiving light by 2016. The ESPRESSO instrument is designed to be even more precise and accurate than HARPS and detect planets around even fainter stars than Gliese 667 C. There's also the Automated Planet Finder Telescope (APF) under construction at the Lick Observatory in California, intended specifically to search for rocky, habitable exoplanets orbiting stars that are less than 100 light years from Earth. There are also planned space telescopes, NASA's Transiting Exoplanet Survey Satellite (TESS) with a launch date in 2017 and the NASA/ESA collaborative James Webb Space Telescope (JWST) in 2018. TESS is meant to be a survey tool, with more precise missions investigating the most promising habitable planetary candidates.

**The TESS satellite will spend two years looking at millions of stars for signs of exoplanets**

> "HARPS has been used to discover more than 130 planets since its installation"

# Inside HARPS

**Secondary mirror**
The secondary mirror in the telescope was replaced in 2004 and uses an f8 Cassegrain focus – the secondary mirror is convex. The 3.6m (140in) designation refers to the size of the telescope's aperture or opening.

**Computer**
This cube houses the computer used to control the telescope's secondary mirror.

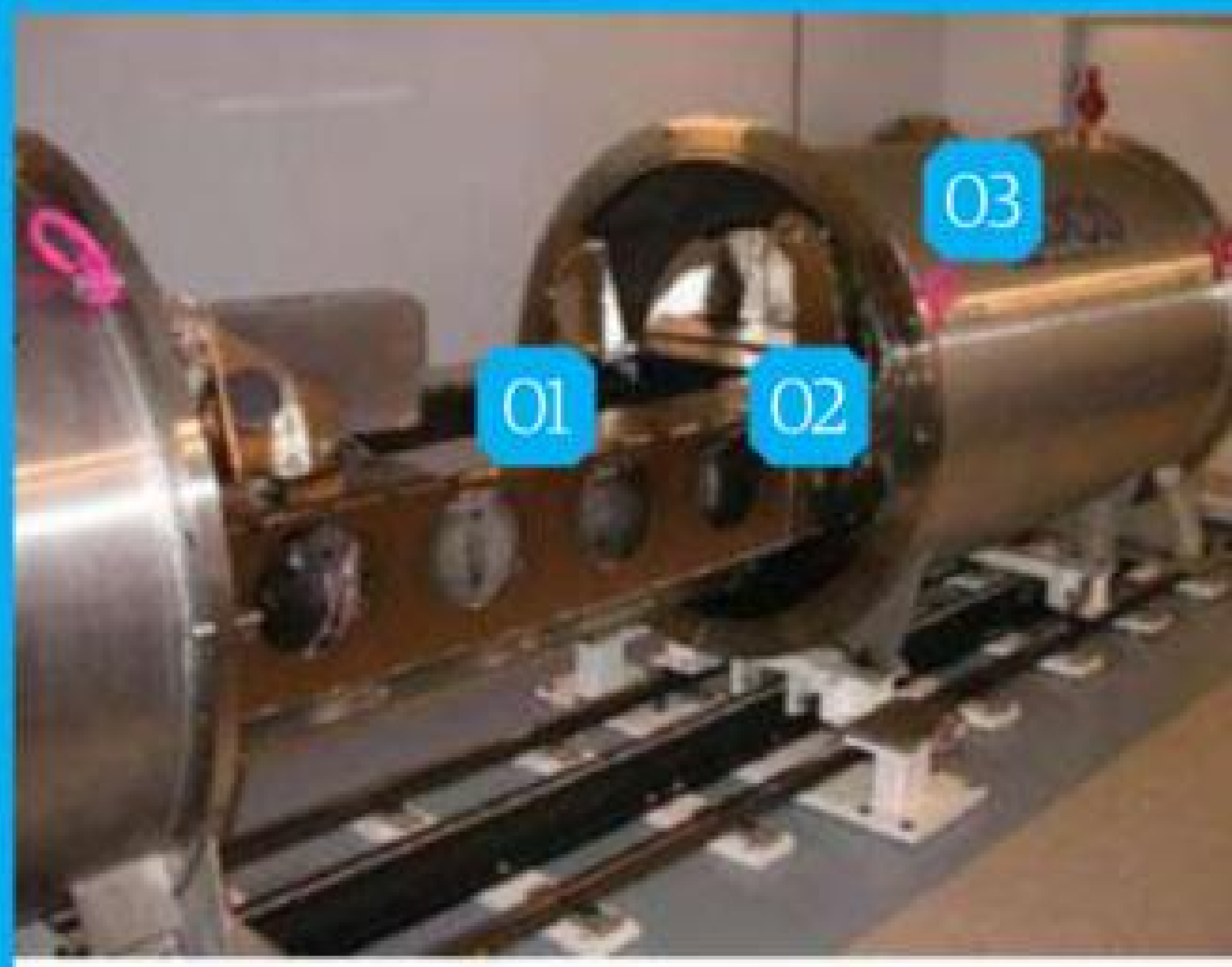
**Primary mirror**
This reflecting telescope uses two mirrors to gather light from the visible and near-infrared part of the electromagnetic spectrum to form an image.

## Mission Profile

### HARPS

**Name:** HARPS
**Mission dates:** 2003 to present
**Location:** La Silla Observatory in Chile

HARPS is a second-generation fibre-fed high-resolution echelle spectrograph, installed on the 3.6-metre telescope at La Silla Observatory. First used to survey stars, HARPS is now focused on the discovery of habitable super-Earths. It discovered over 50 exoplanets in 2011 alone.



**1. Spectrograph**
In this image you can see the echelle grating of the spectrograph, which diffracts the light received by the telescope to create an image of overlapping wavelengths.

**2. Collimator**
The collimator is a huge parabolic mirror (a mirror in the shape of a two-dimensional, symmetrical curve) that is used to narrow the beam of light.

**3. Vacuum tube**
The spectrograph for the HARPS instrument is enclosed in a vacuum vessel to maintain temperature and air pressure. The fibres carrying light from the telescope proper are fed through a hole in the side of the vessel.

NASA; Ron Miller; Teague Soderman; ESO

## 5 AMAZING FACTS ABOUT

# Solar flares

### They release 10 million times more energy than a volcano

A volcanic eruption pales in comparison to a solar flare. In a matter of minutes a solar flare, thought to be caused by magnetic fields, can eject billions of tons of charged particles.

### During peak times there are over 20 solar flares a day

When the Sun is at solar maximum, the period in its 11-year cycle when its activity is at its highest, the Sun can unleash over 100 solar flares every week.

### The fastest ejections reach Earth in less than two days

Solar flares are sometimes accompanied by coronal mass ejections (CMEs), huge outpourings of energy and material that travel at speeds of up to 1,000 kilometres (620 miles) per second.

### They are almost as hot as the core of the Sun

A solar flare can have a temperature of several million Kelvin. For comparison the hottest natural temperature ever recorded on Earth was just 330 Kelvin in Death Valley, California!

### A solar eruption once knocked out a power grid in Québec

In March 1989 a huge CME, one of the largest on record, caused a geomagnetic storm in Earth's atmosphere that crippled the Hydro-Québec power grid in Canada.

This image shows a solar flare erupting on the Sun on 22 January 2012

© NASA

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ORANGUTANS
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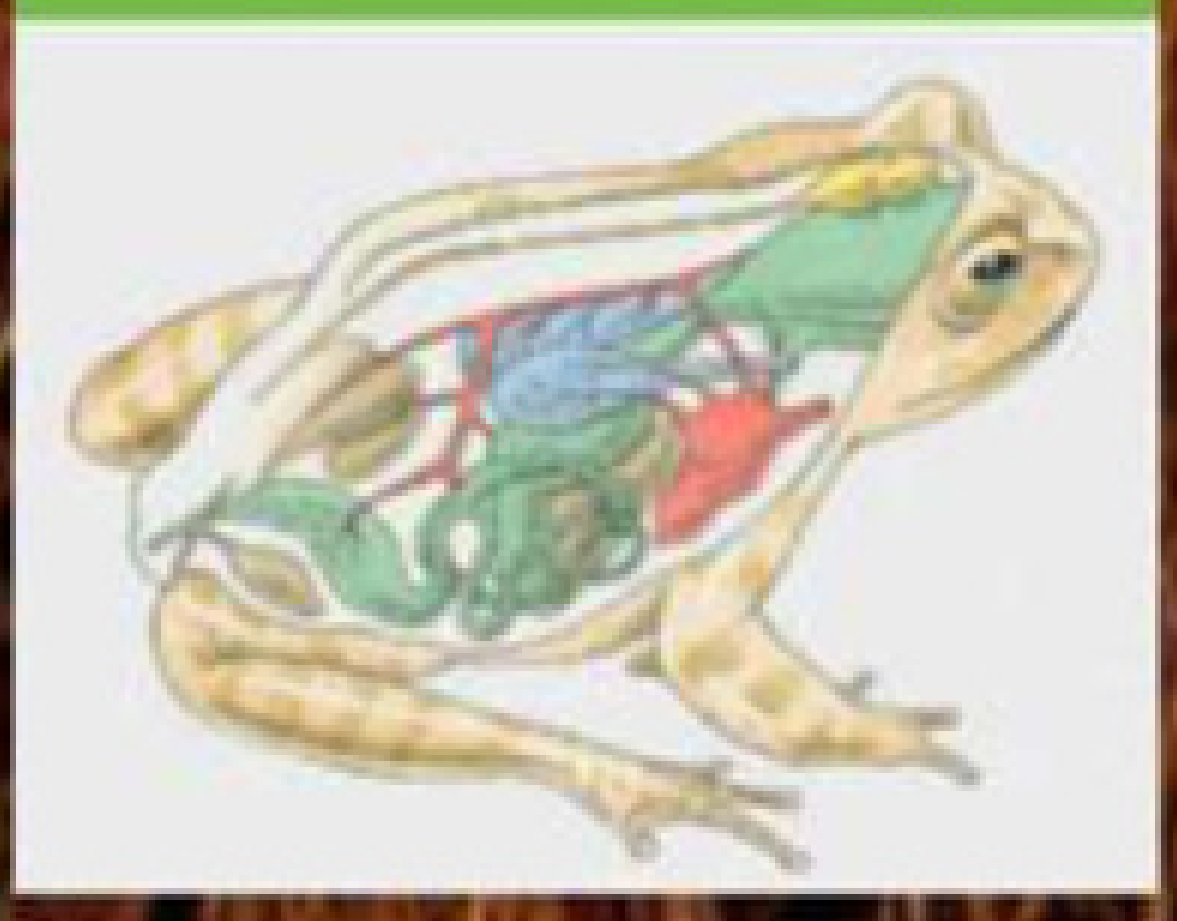

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Worden's first and only mission to space was Apollo 15 in 1971

# Apollo 15's record-breaking pilot

## Often referred to as Earth's most isolated human being, Apollo 15's Command Module pilot Al Worden tells the story of his lonely space flight

**Interviewed by Jonathan O'Callaghan**

**INTERVIEWBIO**

**Al Worden**
**Age: 81**
**No. of missions: 1**
**Time in space: 12 days**

Alfred Merrill Worden was the Command Module pilot for NASA's Apollo 15 lunar mission, which launched on 26 July 1971. He remained in lunar orbit while his fellow crew Dave Scott and Jim Irwin explored the surface for three days, the longest stay on the Moon at the time. From his position in lunar orbit Worden photographed and studied the Moon, and during his orbit he is said to have travelled farther out than anyone else, earning him the accolade of Earth's 'most isolated human being'.

**How did it feel to get selected as an astronaut by NASA in 1966?**

It was probably one of the best days of my life when I got the phone call. You're venturing off into something that very few people have ever done. You've competed with 700 or 800 other [applicants] and you're kind of on top of the pile. It would be like, if you're a soccer fan, getting a call from the best team in the country telling you you're going to be one of their players and they're going to take care of you. It's kind of like that, it'd be a great day but that's when the work starts.

**Were you friendly with the other Apollo astronauts?**

Oh yeah. There was a lot of friendly competition I would say [because] you're trying to get on a flight and you want to beat everybody else, but at the same time you're always training together. Of course, now that we are all retired we have become much more friendly than we were back then.

**What was the training process like?**

There was lots of it; the training kind of covered everything. Not only the engineering and the technical and the flying part, but other parts too like studying geology because we had to know what we were doing once we got up to the Moon. We had a lot of very interesting trips like to the desert, the jungle and Iceland to look at geology but also to look at different climates because there was a survival aspect. If we didn't come back in the atmosphere at the right place, if we lost control and ended up in a jungle in South America for example, we had to learn how to survive long enough for them to come pick us up.

**Were you happy to stay in lunar orbit as the Command Module (CM) pilot, or did you want to walk on the Moon?**

Well, back in those days the way to become a commander on a flight [who walked on the Moon] was to be the CM pilot [first]. Like Dave Scott, he was a CM pilot on Apollo 9 before he became the commander on our flight, and that was basically the rotation.

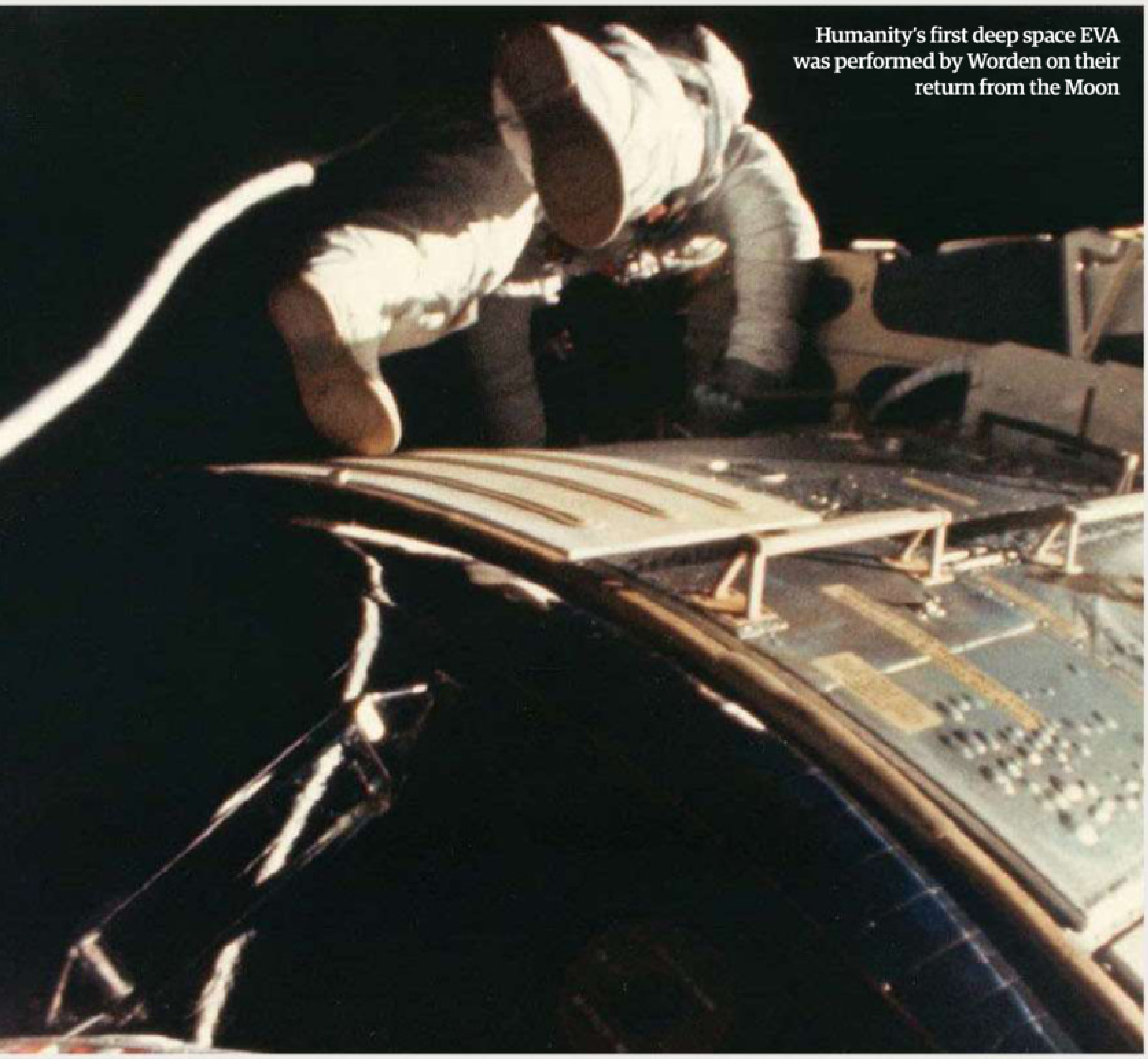
**So were you disappointed when your chance to go to the surface on Apollo 18 was cancelled?**

Oh yeah. There goes the chance to go again. I thought it was kind of dumb at the time, but I understood that NASA had to take that money and put it into the Space Shuttle programme, which wouldn't fly for another ten years, but you've got to build those programmes a long time before they fly.

**Why are you regarded as the most isolated human being of all time?**

I was further away from the guys [on the surface of the Moon] than anybody but we're talking a matter of miles. All the CM pilots had the same deal, they were isolated to a certain extent. I was the first one to go for three full days by myself in lunar orbit and I was a little higher on

> "I think eventually the day will come when we're going to have a spacecraft that will go way, way beyond even the Solar System"



Humanity's first deep space EVA was performed by Worden on their return from the Moon

Worden photographed and mapped 25 per cent of the Moon while in lunar orbit

the back side of the Moon than the others, so I guess they say I'm the most isolated. It's in the Guinness Book of World Records, anyway.

**Were there any moments by yourself when you were worried something might go wrong?**
No, you don't think about those sorts of things on a flight like that. There's always something that could happen, it's like flying an aeroplane, but you don't focus on that, you don't let yourself brood about that stuff.

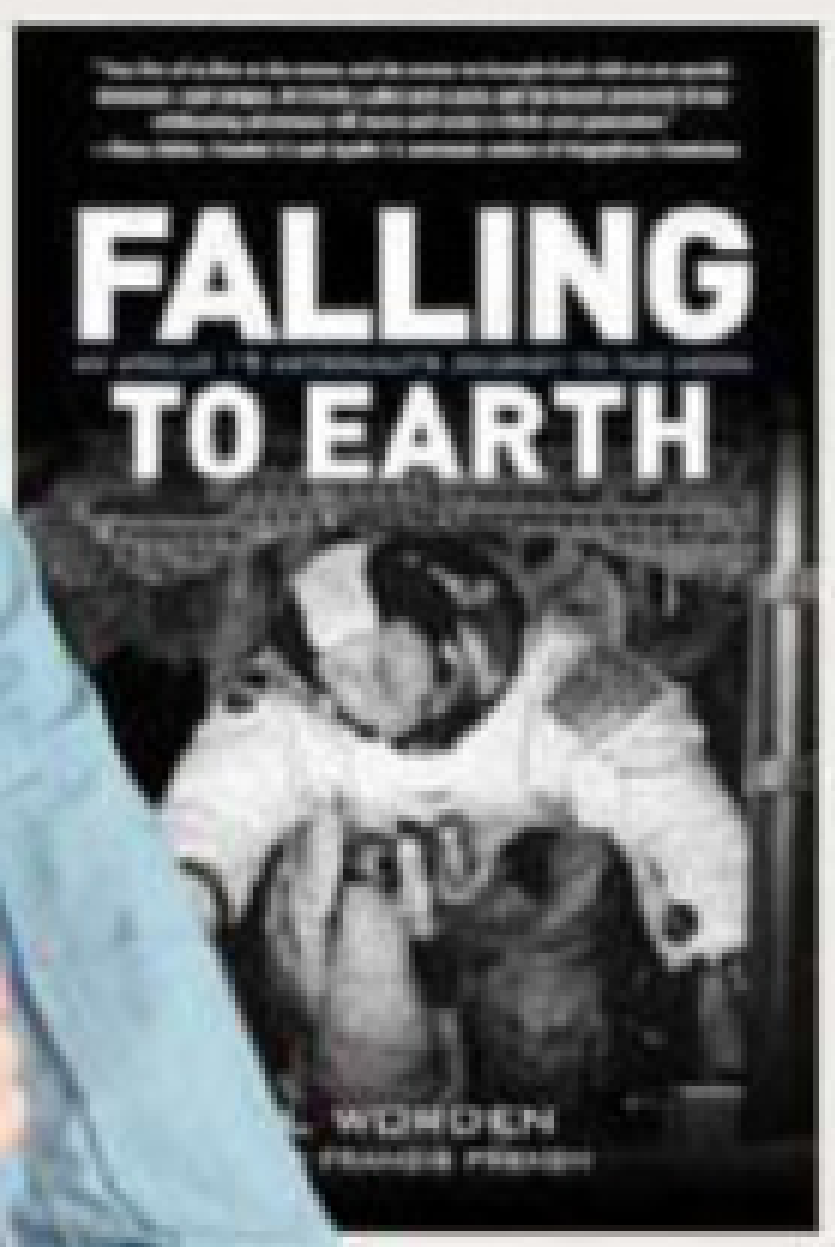
**What were your highlights from the mission?**
I'd say seeing the Moon for the first time, and seeing Earth for the first time from the Moon. Those were pretty spectacular sights.

**Since the Apollo missions, do you think space exploration has progressed forwards?**
Well, it's hard to tell. I think right now they're focusing on getting commercial spacecraft to fly people to the space station, but in the background there is a long-range programme with [the Space Launch System rocket] and [the Orion spacecraft] that will eventually allow us to go beyond Earth orbit, like going to Mars. But right now is not an active part of launching because we're between programmes I guess, and so it's going to be a few years before they get the long-range exploration going with the new spacecraft and I would expect it's going to be another 10 or 15 years before we get back into the exploration business.

**Are we moving in the right direction?**
I think eventually we're going to have to do something a little different than just that gumdrop-shaped capsule because there are some problems with re-entry and that sort of thing, you have to be very careful. But the day will come when we're going to have spacecraft that'll go way, way beyond even the Solar System, so that'll take a different shape. But in the meantime we've got Orion, which is basically an enlarged Apollo spacecraft, and it can do the next step.

**And, finally, tell us about the new flight suits you're releasing.**
We're producing very authentic Apollo jackets, a testament to the programme but also a very high-quality jacket. It's the same weave that was in the [original] Apollo jacket, and the cuffs and the zippers and the stamps are all authentic from the same manufacturer that applied those things to the flight jackets 40 years ago. It harks back to an era in spaceflight that was really wonderful. ●

## Falling To Earth



Hardback
Available from: www.amazon.co.uk
Price: £21.99/$29.95
Worden's autobiography *Falling To Earth* tells the story of his time at NASA, and is available now. He is also releasing a limited number of authentic Apollo astronaut jackets (pictured), which will be available from www.alexanderleathers.com.

© NASA; Steven Pidcock

# Earth's BIGGEST IMPACT CRATERS

For billions of years our planet has been a target for massive space rocks, so where are the really huge craters? **All About Space** speaks to two prominent crater experts on the biggest impacts to shake planet Earth

Written by Ben Biggs

Barringer, or 'Meteor Crater', is comparatively small at around 1.2km (0.74mi) but due to its remarkable geology, it was used to train Apollo Moon astronauts by NASA in the Sixties

Geologically speaking, Earth is one of the more dynamic planets in the Solar System. A comparatively thin and cool crust floats in great continental plates on several thousand kilometres of molten and semi-molten rock, grinding, overlapping and subducting under each other over millions of years. On top of that, we have a relatively thick atmosphere and complex weather processes that can erode tall mountains down to a small nub, given enough time; over 70 per cent of our planet is covered in water, the remaining 30 per cent is mostly covered in vegetation or buried beneath snow, sand or soil and it's inhabited by millions of life forms, including billions of humans who cover large swathes of land in concrete and steel structures. So it's no wonder that, next to an inert and blasted satellite like the Moon or a planet as pebble-dashed as Mars, Earth seems to have got through the trigger-happy Late Heavy Bombardment period of the early Solar System relatively unscathed.

"The record of impact cratering on Earth is terribly incomplete," Dr David Kring of the Lunar and Planetary Institute, Texas, tells us. "Most impact craters have been destroyed by other geologic processes. The Moon is a better proxy for the impact rate in our part of the Solar System. Studies of the Moon suggest over 3 to 4 million impact craters larger than one kilometre [0.6 miles] in diameter have been produced in Earth history. Some of the oldest impact craters produced during the first half-billion years of Earth history could have had diameters in excess of 1,000 kilometres [620 miles] and thus, nearly continental in scale. The largest impact basin on the Moon is 2,500 kilometres [1,550 miles] in diameter, the Earth likely had at least one crater that size, if not larger."

Scientists today know that the 180 confirmed impact craters on our planet are just a fraction of the total that have been lost to the ravages of several billion years of planetary evolution. Some of the Earth's biggest known craters that include the Vredefort crater in South Africa, Sudbury in Canada and, of course, the famous Chicxulub crater in Mexico's Yucatán Peninsula, don't even rate among the top 20 in the Solar System. And even the oldest only dates back to around the halfway point in Earth's history, 2 billion years ago.

"An important question to ask," says Dr Gareth Collins, a specialist in impact cratering and senior lecturer at Imperial College, London, "is: 'why does the Moon have so many more craters than Earth?' The honest answer is that we don't know but I'm firmly of the belief that the Earth did experience impacts of that size very early in its history, we just don't have any evidence of that on Earth remaining. The thing to keep in mind is that all of these craters, every single one on the Moon that's bigger than Chicxulub, formed in the first billion years and probably the first few hundred million years of the Moon's lifetime. We don't have any rocks on Earth that are that old, so we don't have any evidence on Earth of that time in its history."

The power of an impactor relative to its size often surprises people. In February 2013, the Chelyabinsk meteor exploded high in the atmosphere over Russia with the energy of over half a megaton of TNT (over 30 times the energy released by the

Hiroshima bomb), creating an intensely bright flash and momentary searing heat, followed by a shockwave that blew the glass out of windows and damaged buildings in several cities in the region. This explosion was created by an object with a diameter of no more than 20 metres (66 feet) but it's the mass and the velocity of the Chelyabinsk meteor that's critical here: before breaking up it was around 10,000 tons and was blazing through the Earth's atmosphere at about 18.6 kilometres (11.6 miles) per second when it exploded. That's a fairly average velocity, as far as meteors go.

"Impact velocity is very important," explains Dr Collins. "Everything that hits the upper atmosphere is travelling at least 11 kilometres [6.8 miles] per second, which is the escape velocity of Earth and the fastest asteroid is travelling about 30 kilometres [18.6 miles] per second… we're hit by everything from objects the size of a grain of sand up to the size of a city - or we have been over the past few hundred million years. That's a huge variation in impact and mass and while small things have no detectable effect, the very largest things can be absolutely catastrophic.

"There's a size range of maybe about ten metres [33 feet] to 100 metres [328 feet] where the impactor essentially explodes in the atmosphere. It's classed like Chelyabinsk and also the Tunguska event over 100 years ago in Siberia. Moving up in size, you start to form craters on the surface. In that case the impactor makes it through the atmosphere. It might be disrupted in some way but it essentially makes it to the surface without losing its speed or energy, the explosion then forms a big crater 10 to 20 times bigger than the impactor itself. Debris is thrown out of the crater onto the surrounding plane and is lofted up into the atmosphere."

The impactors that created Earth's biggest craters were certainly a lot smaller than the gaping holes they left in the surface but they were still terrifyingly massive. Like the basins they've left behind, the size of the objects that hit prehistoric Sudbury or Chicxulub is in dispute but they could easily have been around ten kilometres (6.6 miles) wide with a mass in excess of a trillion tons.

"We've been hit by things in the past at a range of different sizes," continues Dr Collins. "Chicxulub is one of the biggest things that ever happened on Earth and that was probably up to ten miles [16 kilometres] across. We have a lot more craters on Earth that were formed by objects a mile [1.6 kilometres] across and even more that were formed by something a few hundred metres or so.

"At this threshold, the material that's been thrown out of the crater is able to disperse all the

"We've been hit by things in the past at a range of different sizes. Chicxulub is one of the biggest"

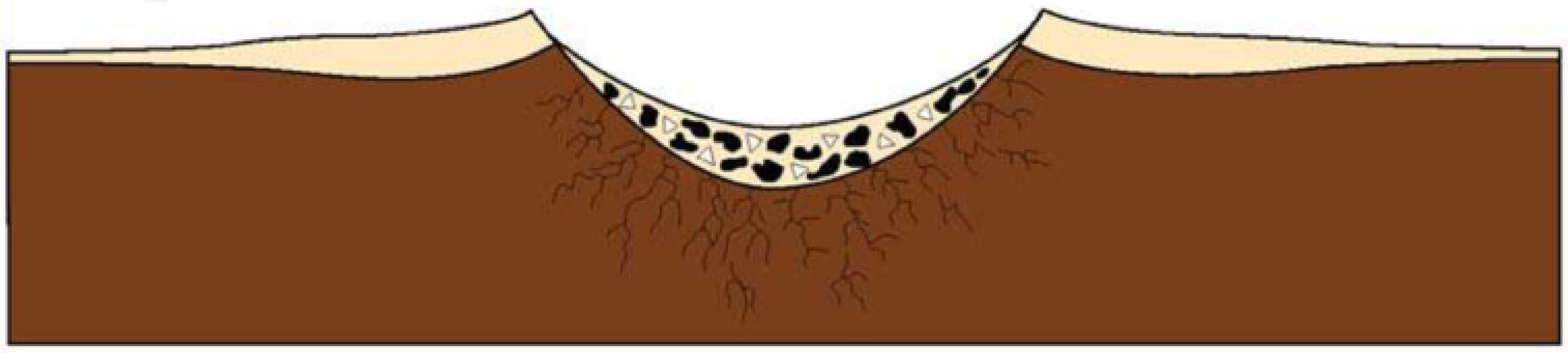
## Where do Earth impactors come from?

**Sea impact**
Just because an extraterrestrial object lands in the sea, doesn't mean its effects are mitigated. Even small objects travelling at meteoric speeds can deliver enormous amounts of energy on impact, and larger bodies can create huge tidal waves while punching right through to the ocean floor.

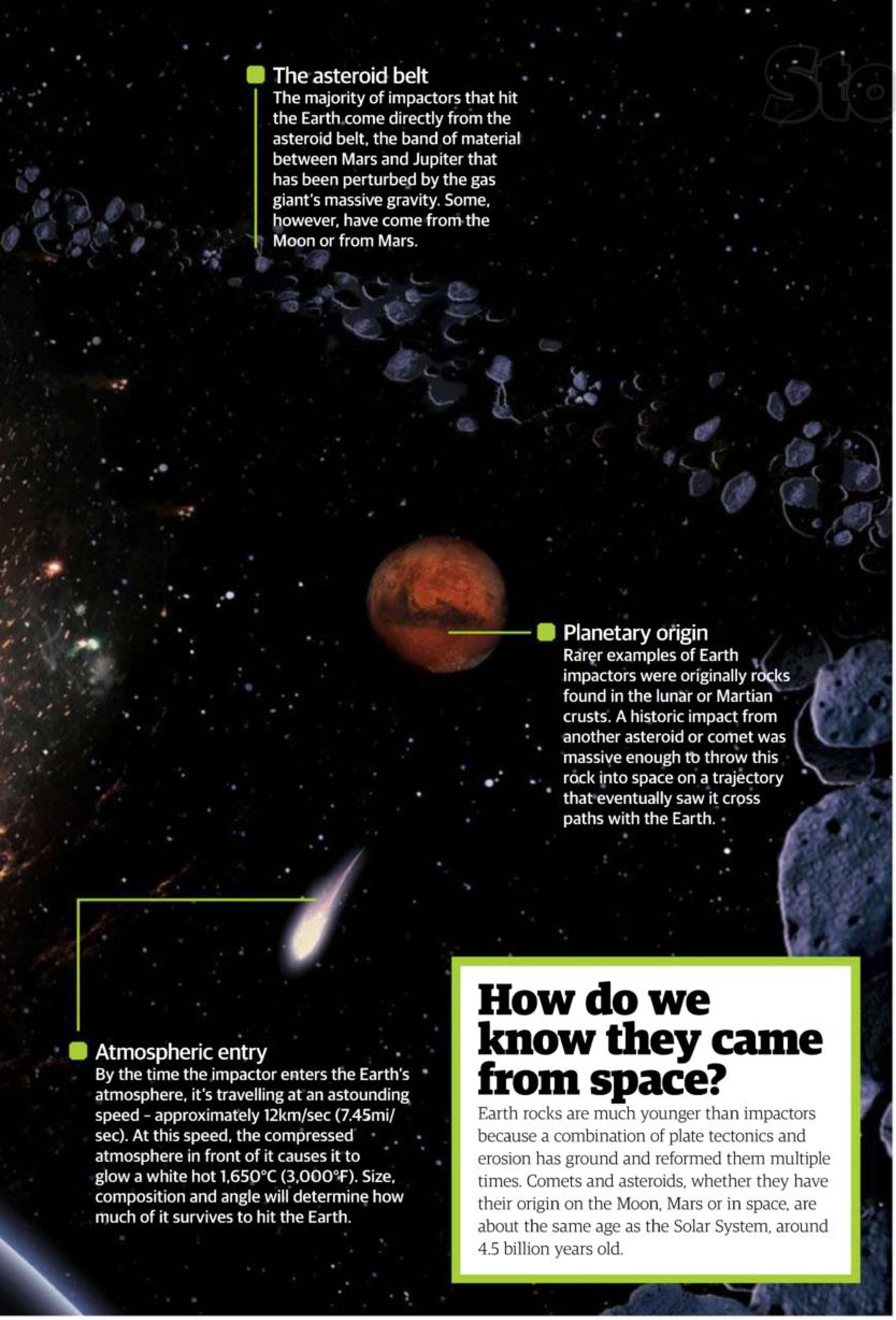
**Land impact**
A high-velocity, massive object hitting land deforms the ground and throws out a shockwave that can produce powerful earthquakes. Within seconds, rocks in the area melt and vaporise as a crater that's significantly larger than the meteorite that created it.

## Impact crater types

### Simple



Simple impact craters are smaller than their complex siblings. They have a ratio of depth to diameter of up to 1:7 and are distinctly bowl-shaped, like the Barringer crater in Arizona. Craters become complex when they reach a certain diameter and the greater the gravity of the planet, the smaller this threshold is.



**The asteroid belt**
The majority of impactors that hit the Earth come directly from the asteroid belt, the band of material between Mars and Jupiter that has been perturbed by the gas giant's massive gravity. Some, however, have come from the Moon or from Mars.

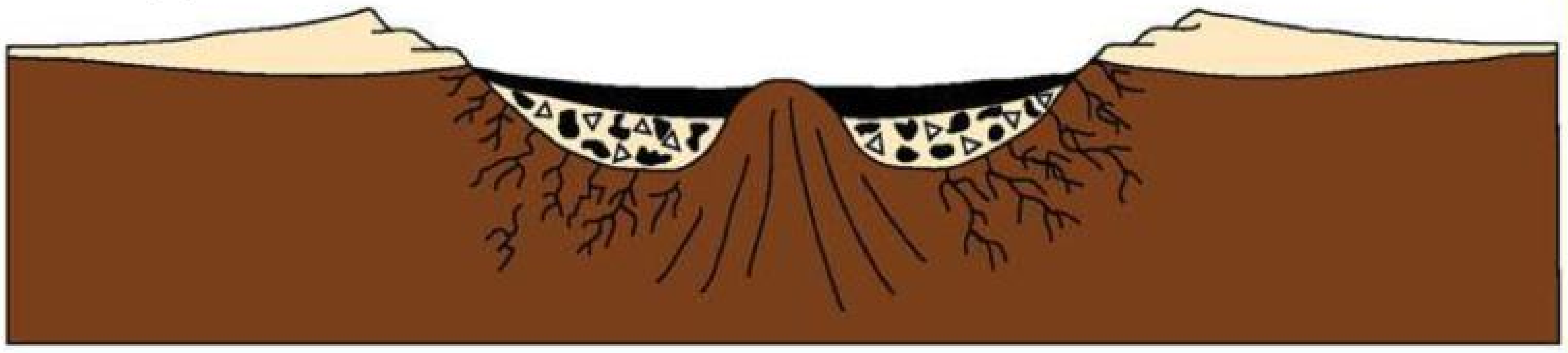
**Planetary origin**
Rarer examples of Earth impactors were originally rocks found in the lunar or Martian crusts. A historic impact from another asteroid or comet was massive enough to throw this rock into space on a trajectory that eventually saw it cross paths with the Earth.

**Atmospheric entry**
By the time the impactor enters the Earth's atmosphere, it's travelling at an astounding speed - approximately 12km/sec (7.45mi/sec). At this speed, the compressed atmosphere in front of it causes it to glow a white hot 1,650°C (3,000°F). Size, composition and angle will determine how much of it survives to hit the Earth.

## How do we know they came from space?

Earth rocks are much younger than impactors because a combination of plate tectonics and erosion has ground and reformed them multiple times. Comets and asteroids, whether they have their origin on the Moon, Mars or in space, are about the same age as the Solar System, around 4.5 billion years old.

## Complex



Craters between two to four kilometres (1.2 to 2.5 miles) wide and upwards form complex structures in Earth gravity. Here, a central peak is formed as the crater floor rebounds after the shock of the impact. Many large impact structures on Earth have been eroded by the elements, deformed by plate tectonics or buried.

## Target: Earth

### What happens when an object from space impacts the Earth?

There are an enormous range of factors that dictate exactly what happens when an object - be it an icy comet or dense asteroid - enters Earth atmosphere. Comets typically travel at three times the velocity of meteors, but a metallic meteor can be eight times as dense. The size and its angle can affect whether it explodes as an airburst, fragments or impacts the Earth largely intact. The depth of water or the density of rock it impacts will help determine the crater it leaves.

**Impactor type: Metallic**
Size: 1km (0.6mi) diameter
Target: Sea (500m/1,600ft deep)
Result: Strikes intact

The impactor strikes the sea without breaking up. It sends a huge tsunami thousands of kilometres across the ocean and impacts the sea bed creating a crater 19.2 kilometres (11.9 miles) in diameter.

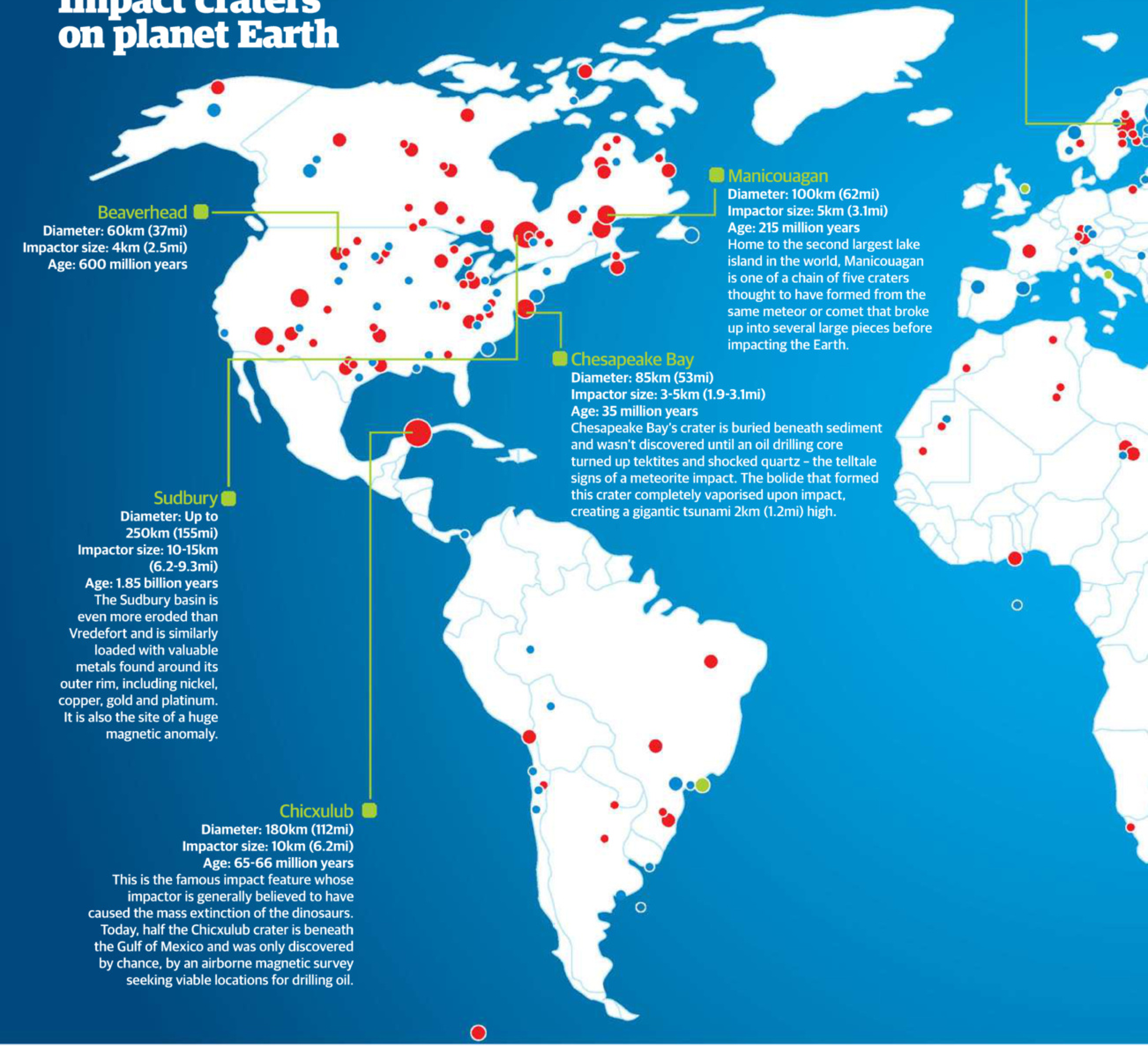
**Impactor type: Porous rock**
Size: 100m (328ft) diameter
Target: N/A
Result: Airburst

The meteorite never makes landfall: it begins to break up high in the atmosphere before exploding at around 2.5 kilometres (1.5 miles) altitude in an airburst equivalent to about 26 megatons of TNT.

**Impactor type: Icy comet**
Size: 500m (1,600ft) diameter
Target: Land (sedimentary rock)
Result: Fragments

The comet breaks up in the atmosphere and hits the ground fragmented. Its impact equals a 16.5 gigaton TNT explosion, vaporising rock and creating a crater 8.5 kilometres (5.3 miles) wide.

# Impact craters on planet Earth



**Siljan Ring**
**Diameter: 52km (32mi)**
**Impactor size: 1-2km (0.6-1.2mi)**
**Age: 377 million years**

**Manicouagan**
**Diameter: 100km (62mi)**
**Impactor size: 5km (3.1mi)**
**Age: 215 million years**
Home to the second largest lake island in the world, Manicouagan is one of a chain of five craters thought to have formed from the same meteor or comet that broke up into several large pieces before impacting the Earth.

**Beaverhead**
**Diameter: 60km (37mi)**
**Impactor size: 4km (2.5mi)**
**Age: 600 million years**

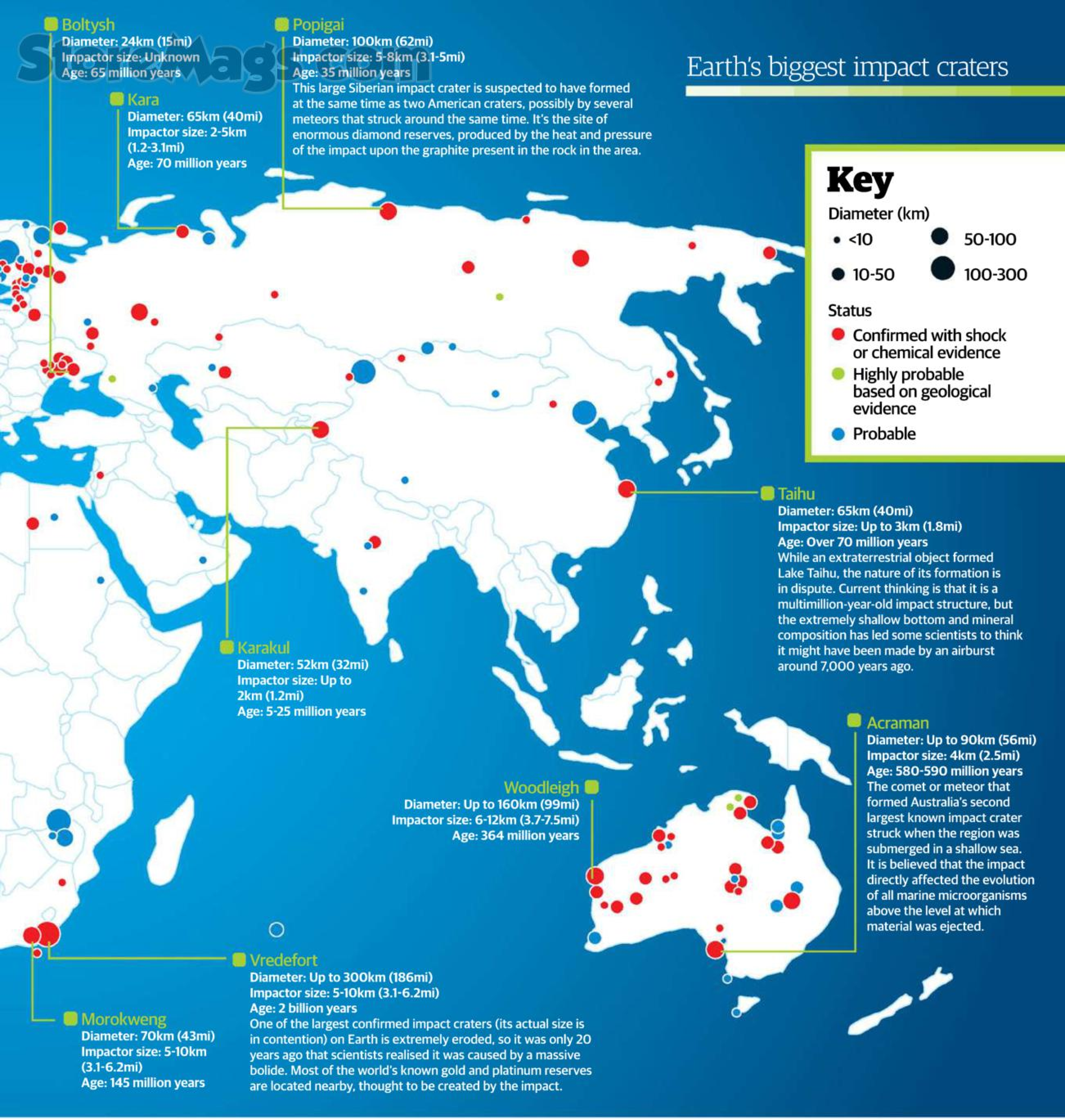
**Chesapeake Bay**
**Diameter: 85km (53mi)**
**Impactor size: 3-5km (1.9-3.1mi)**
**Age: 35 million years**
Chesapeake Bay's crater is buried beneath sediment and wasn't discovered until an oil drilling core turned up tektites and shocked quartz – the telltale signs of a meteorite impact. The bolide that formed this crater completely vaporised upon impact, creating a gigantic tsunami 2km (1.2mi) high.

**Sudbury**
**Diameter: Up to 250km (155mi)**
**Impactor size: 10-15km (6.2-9.3mi)**
**Age: 1.85 billion years**
The Sudbury basin is even more eroded than Vredefort and is similarly loaded with valuable metals found around its outer rim, including nickel, copper, gold and platinum. It is also the site of a huge magnetic anomaly.

**Chicxulub**
**Diameter: 180km (112mi)**
**Impactor size: 10km (6.2mi)**
**Age: 65-66 million years**
This is the famous impact feature whose impactor is generally believed to have caused the mass extinction of the dinosaurs. Today, half the Chicxulub crater is beneath the Gulf of Mexico and was only discovered by chance, by an airborne magnetic survey seeking viable locations for drilling oil.

way around the globe, rather than being contained within a few crater radii of the impact. It's able then to encircle and rain back down over the globe. That's really important because if that threshold didn't exist, even Chicxulub would only have affected the northern United States. A continental scale of damage would have been the maximum it could have achieved. But once it's able to throw material into space and around the globe, then you really start to have a global effect on the climate. This is when you start to have real unknowns because it's a complex problem. Lots of people have looked at different parts with no real consensus of exactly what it was, particularly Chicxulub, that did the most damage."

These potential planet-killers span a range of ages, from the 2 billion years-plus Yarrabubba crater in Western Australia, to the relatively recent Popigai in Russia, a big baby at just 35 million years old. They're frequently linked with the 'big five' mass extinction events that we have evidence of on Earth, but the only confirmed link between a global mass extinction of this kind and an extraterrestrial impact, is the Chicxulub event and the Cretaceous-Tertiary boundary extinction that sealed the fate of the dinosaurs. It was Dr Kring's team that made this connection, which took him and his team far from the point of impact: "Once an impact crater has been eroded or subducted, the only surviving trace may be debris that it ejected over a larger area… the Chicxulub impact event produced debris that



## Earth's biggest impact craters

**Key**

Diameter (km)

- • <10
- ● 10-50
- ● 50-100
- ● 100-300

Status

- 🔴 Confirmed with shock or chemical evidence
- 🟢 Highly probable based on geological evidence
- 🔵 Probable

**Boltysh**
Diameter: 24km (15mi)
Impactor size: Unknown
Age: 65 million years

**Kara**
Diameter: 65km (40mi)
Impactor size: 2-5km (1.2-3.1mi)
Age: 70 million years

**Popigai**
Diameter: 100km (62mi)
Impactor size: 5-8km (3.1-5mi)
Age: 35 million years
This large Siberian impact crater is suspected to have formed at the same time as two American craters, possibly by several meteors that struck around the same time. It's the site of enormous diamond reserves, produced by the heat and pressure of the impact upon the graphite present in the rock in the area.

**Taihu**
Diameter: 65km (40mi)
Impactor size: Up to 3km (1.8mi)
Age: Over 70 million years
While an extraterrestrial object formed Lake Taihu, the nature of its formation is in dispute. Current thinking is that it is a multimillion-year-old impact structure, but the extremely shallow bottom and mineral composition has led some scientists to think it might have been made by an airburst around 7,000 years ago.

**Karakul**
Diameter: 52km (32mi)
Impactor size: Up to 2km (1.2mi)
Age: 5-25 million years

**Woodleigh**
Diameter: Up to 160km (99mi)
Impactor size: 6-12km (3.7-7.5mi)
Age: 364 million years

**Acraman**
Diameter: Up to 90km (56mi)
Impactor size: 4km (2.5mi)
Age: 580-590 million years
The comet or meteor that formed Australia's second largest known impact crater struck when the region was submerged in a shallow sea. It is believed that the impact directly affected the evolution of all marine microorganisms above the level at which material was ejected.

**Vredefort**
Diameter: Up to 300km (186mi)
Impactor size: 5-10km (3.1-6.2mi)
Age: 2 billion years
One of the largest confirmed impact craters (its actual size is in contention) on Earth is extremely eroded, so it was only 20 years ago that scientists realised it was caused by a massive bolide. Most of the world's known gold and platinum reserves are located nearby, thought to be created by the impact.

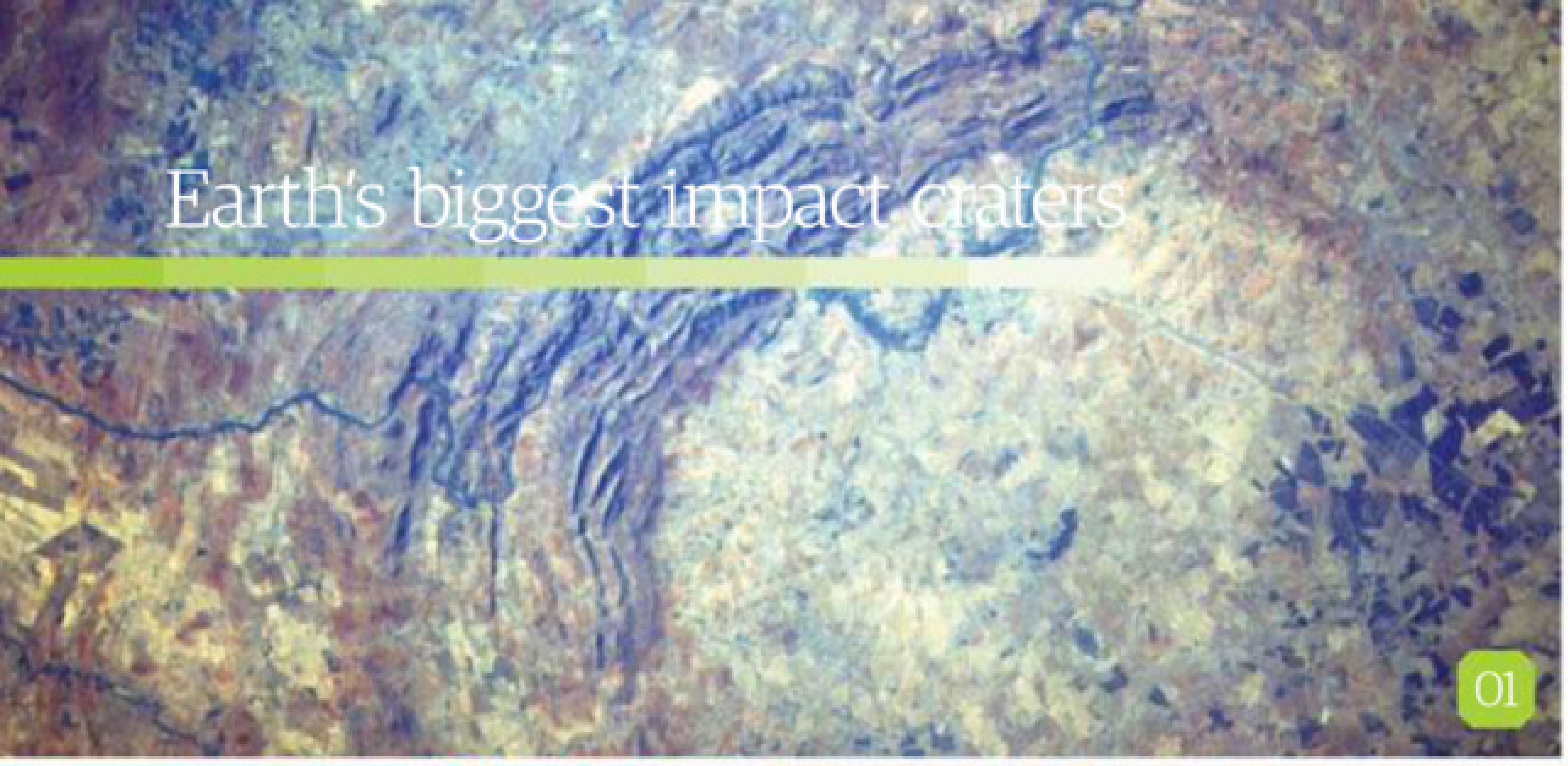
**Morokweng**
Diameter: 70km (43mi)
Impactor size: 5-10km (3.1-6.2mi)
Age: 145 million years

> "The only surviving trace may be debris that it ejected over a larger area"

blanketed the entire Earth. While the Chicxulub impact structure is now hidden beneath about one kilometre (0.6 miles) of rock, over one hundred outcrops of its impact ejecta can be found on the surface of the Earth.

"Our team's strategy was to locate debris ejected from the hypothesized impact site and then trace that debris to the crater. The closer one is to the crater, the thicker the debris. There were two eureka moments. First, we found a deposit of debris in Haiti that was about 50 times thicker than debris found anywhere else in the world. That told us that the impact occurred somewhere in the Gulf of Mexico or proto-Caribbean region. We then began searching for a circular structure in that region. We located a description of a buried volcanic complex in Mexico and thought it looked suspicious. We obtained two fragments of rock from a previous drilling project and I found it contained shocked quartz and impact melt particles, two substances that proved the structure

## Earth's biggest impact craters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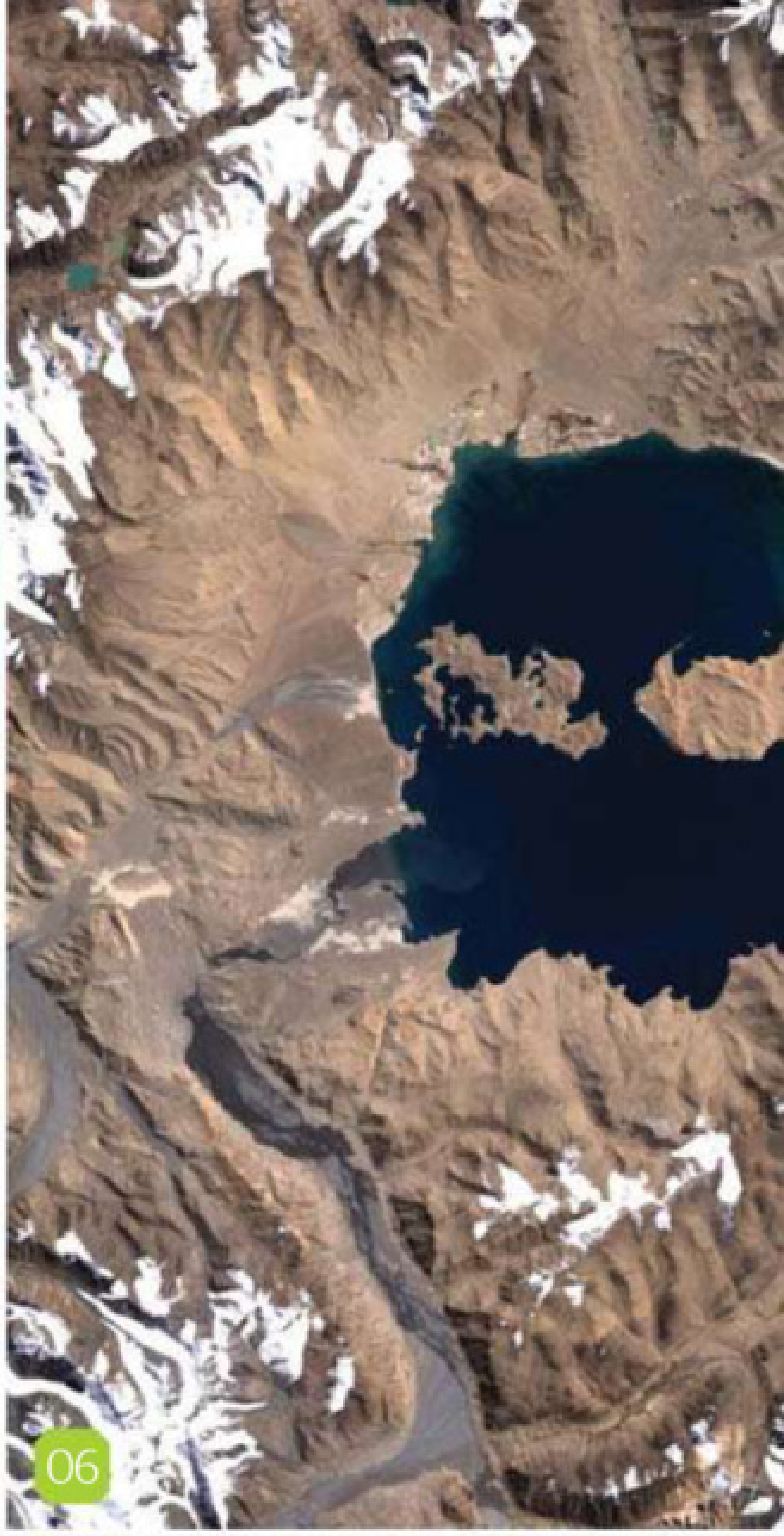
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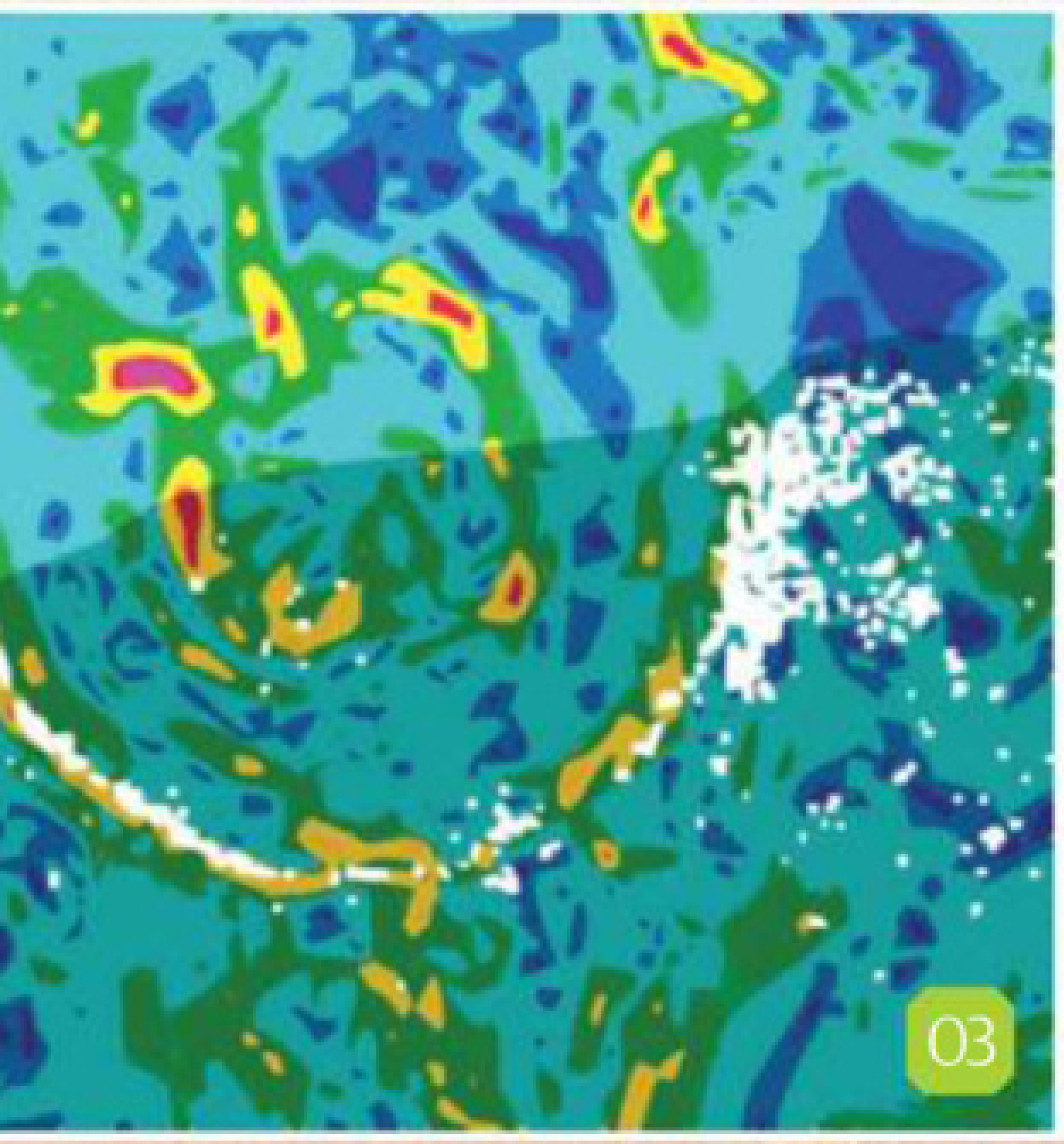
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was an immense impact crater rather than a buried volcanic complex."

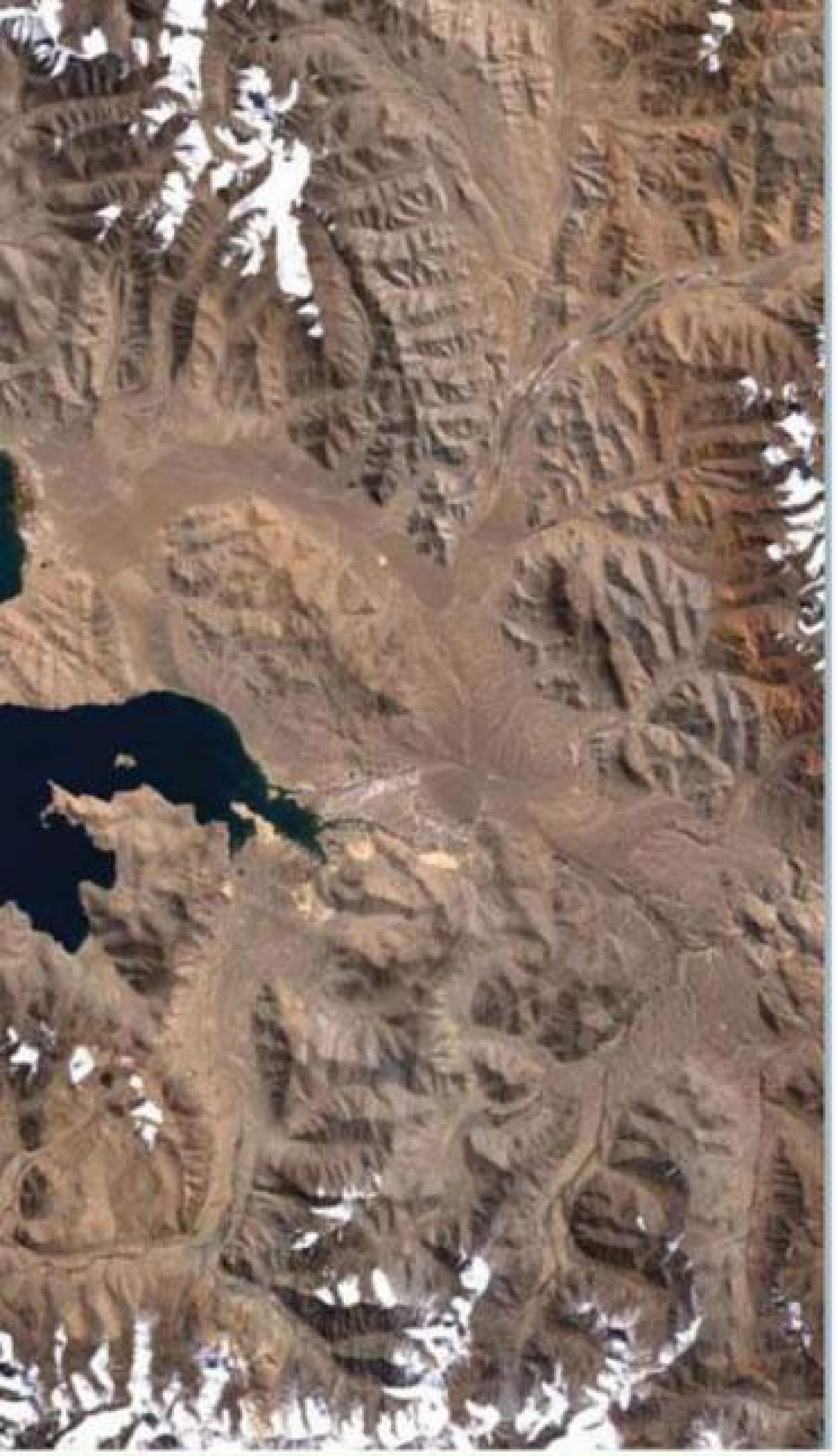
It's not these huge impact events that scientists are really concerned about, however. The kind of devastating asteroids targeting Earth that made our biggest known craters strike less than once every million years. Besides that, with today's technology we're easily able to detect and track these monsters well in advance: even if we're not totally ready to defend against a massive asteroid on a potential Earth-impact trajectory, we will have years, even decades, of forewarning to prepare for one. It's the smaller impactors, the kind that produce the likes of the relatively small, 1.2-kilometre (0.75-mile) Barringer crater in Arizona, which are cause for some consternation. Barringer was created by a 50-metre (150-foot) diameter lump of nickel-iron weighing in at about 300,000 tons that exploded with the force of 2.5 megatons of TNT. These objects are small enough to slip under the radar until it's too late to do anything about them, yet they would be devastating if they hit a populated area and happen frequently enough in Earth's history - typically once every 5,000 years or so.

While most of our biggest craters have succumbed to the Earth's elements, Dr Collins believes there are still some major impacts left to be discovered. Oddly enough though, even if we're standing on top of a really huge crater, recognising it for what it is will pose a problem. The biggest known impacts in the Solar System, such as the ones that created the Moon's South Pole-Aitken Basin and Hellas Planitia on Mars, get so hot that they melt a key diagnostic feature scientists look for - its shock metamorphism: "The problem on any planet is that when an impact gets big enough, the entire floor of the crater gets covered in a thick layer of rock that was melted by the impact. If this happens the huge melt sheet will remove any evidence of shock, just melt it all away. So the biggest crater on Earth might end up looking like a very large melt province and the key diagnostic features of an impact might be missed. It's an uncomfortable situation to be in because, how do we prove that this was an impact crater and not a large volume of rock that was melted by Earth's interior?"

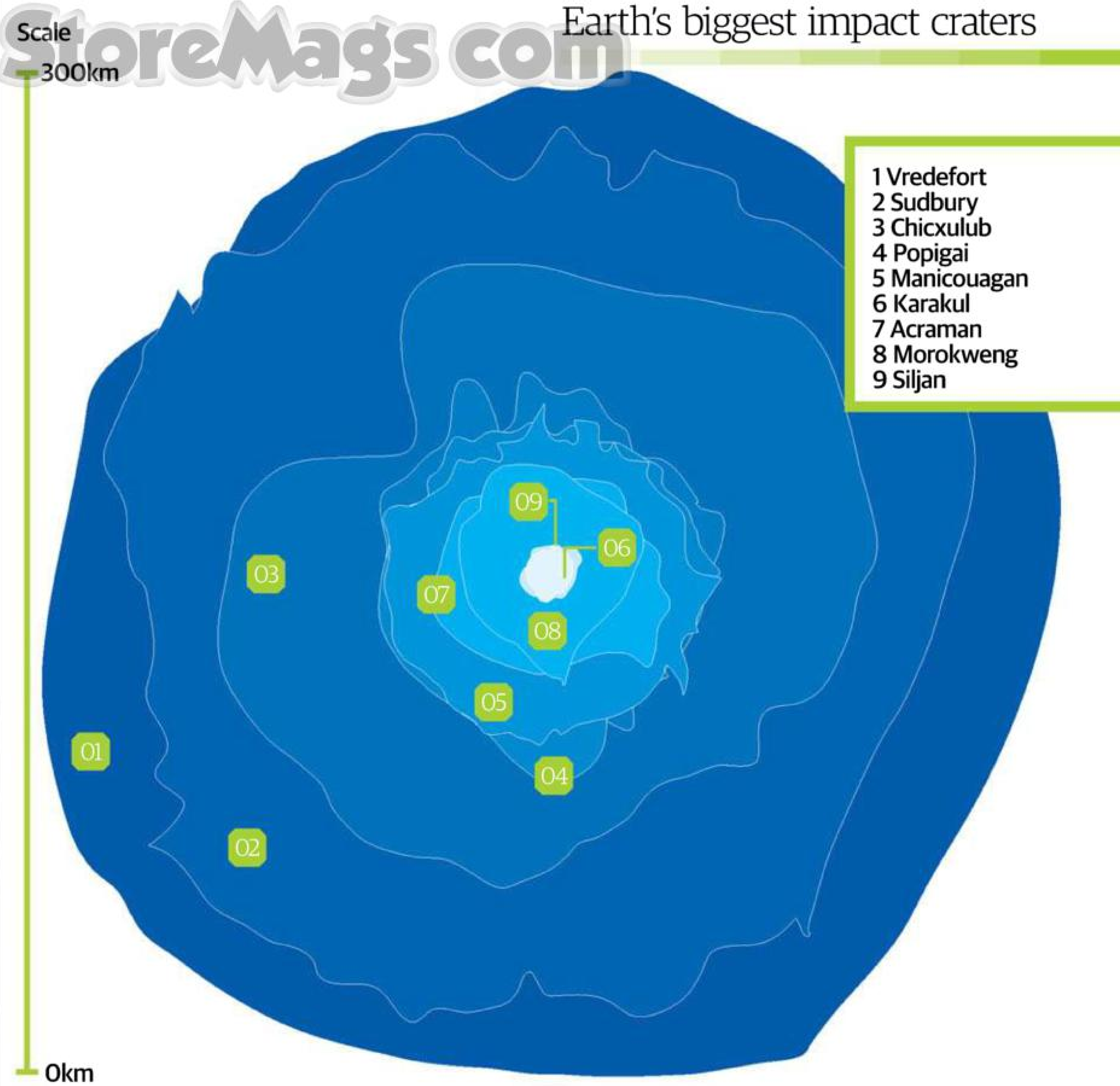
Clearly, by studying impact craters on Earth where they're easily accessed, we can learn more about the geological history of other bodies. Earth is just another planet in the Solar System, after all, and subject to the same physical laws. "What we can start to do," says Dr Collins, "is to go to other planets and look at the craters, where we can start to understand what the internal structure of that planet might be... we think that through studying craters on Earth, [we can see] there's a very weak layer underneath the surface of Europa that's affecting the creation of those craters. The big craters are really shallow, so we can start to infer something about the depth of that weak layer, whether it is water or very weak ice."

"The most important geologic process affecting planetary surfaces throughout the Solar System is impact cratering," concludes Dr Kring. "We've learned that impact events can occur in pulses and one of the biggest pulses may have been about 4 billion years ago. That event resurfaced most planets, including Earth and may have had an effect on the early evolution of life on our planet. While we have few surviving relicts of those events on Earth, studies of Earth's craters provide the baseline data needed to interpret the geologic history of other planets." ●

> "One of the biggest pulses may have been about 4 billion years ago. That resurfaced most planets, including Earth"



## Earth's biggest impact craters



Maniitsoq, on the west coast of Greenland, where a huge, ancient and suspiciously crater-like geological structure has been discovered

# Even bigger Earth impacts?

There are a few suspected impact craters around the world that, pending further evidence and general confirmation by the scientific community, could dwarf even Chicxulub and Vredefort. The Wilkes Land crater, a structure underneath the ice cap of Wilkes Land, East Antarctica, is proposed to be nearly 500 kilometres (311 miles) wide, although there's no conclusive evidence that it exists. Shiva is a hypothetical Indian crater, also 500 kilometres wide, found underneath the continental shelf, while an unnamed 600-kilometre (373-mile) diameter crater could exist in the Australian outback. A large crater-like structure was also discovered in Greenland last year, which had no compelling shock evidence but had other features consistent with a massive impact. If the origin of the 100-kilometre (62-mile) Maniitsoq crater is confirmed as extraterrestrial, then it will be our oldest impact crater at around 3 billion years.

© Alamy; NASA; Peters & Zabransky

This image was snapped by the Danish 1.54-metre (5.05-foot) telescope located at ESO's La Silla Observatory in Chile

# Inside the Archer

## This stunning nebula sheds new light on the famous Sagittarius constellation

Found 5,000 light years from Earth in the constellation Sagittarius (the Archer), NGC 6559 is a cloud of dust and gas that plays host to stellar formation. Most of the clouds of NGC 6559 are made of hydrogen, the raw material of star formation, and therefore they can collapse under gravity and give birth to new stars. In turn, these new stars energise the hydrogen gas, producing the red cloud in the centre of the image known as an emission nebula.

Within the region are also solid particles of dust consisting of heavier elements including carbon and silicon. The blue section of the image, just a few light years across, shows light from young stars being scattered by these particles of dust, with the blue effect resulting from shorter wavelengths of light being reflected. The dark patches of the image are regions where the density of the dust blocks the light behind it.

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## YOUR QUESTIONS ANSWERED BY OUR EXPERTS

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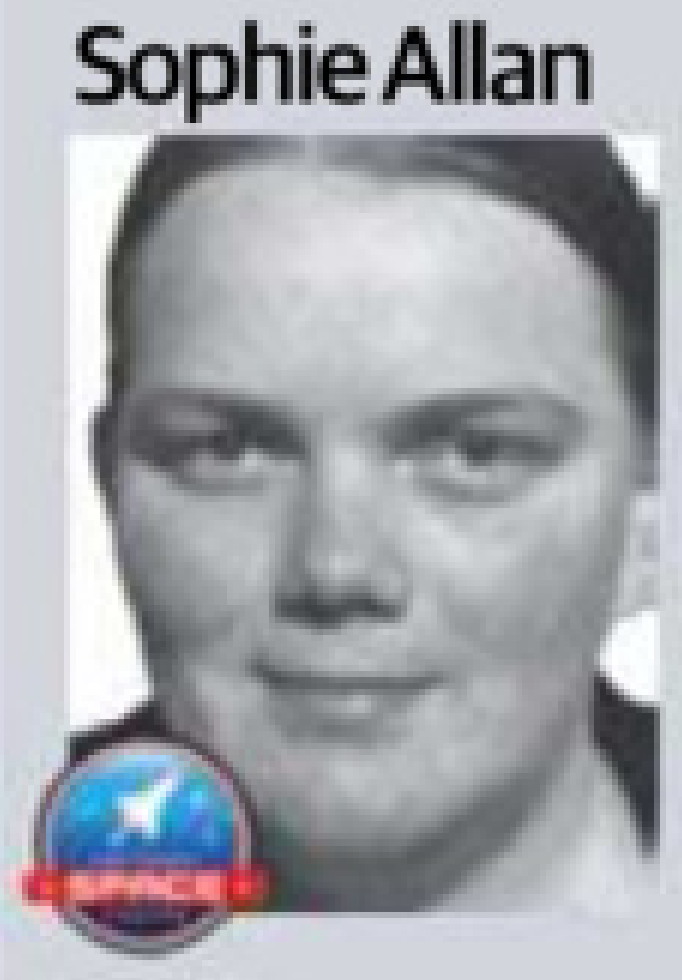
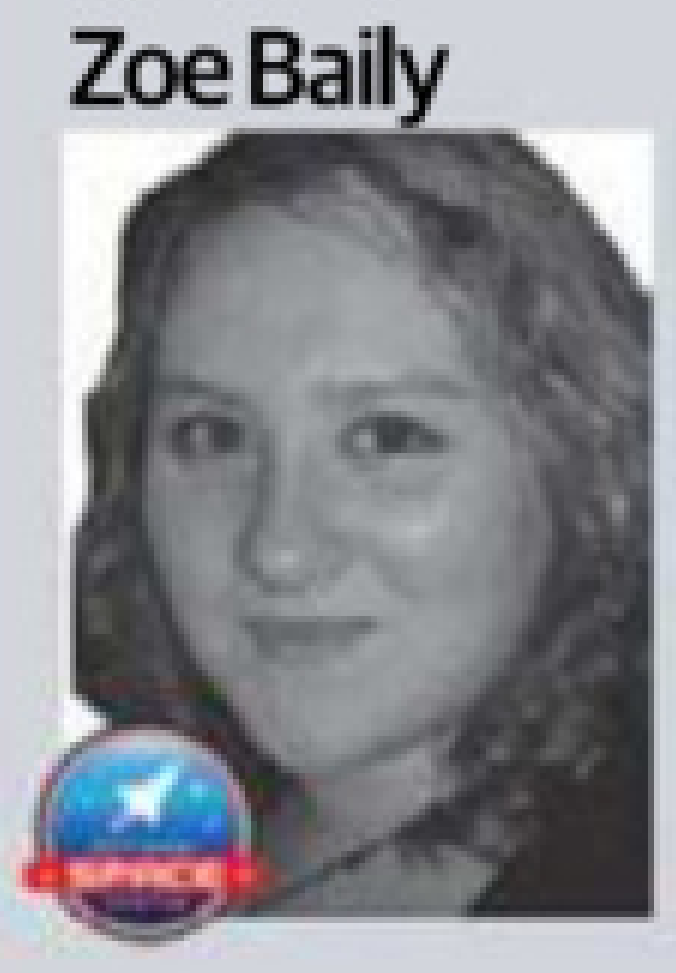
**Sophie Allan**



**National Space Academy Education Officer**
■ Sophie studied astrophysics at university. She has a special interest in astrobiology and planetary science.

**Zoe Baily**



**National Space Centre**
■ Zoe holds a Master's degree in interdisciplinary science and loves the topic of space as it brings together many different scientific disciplines.

**Josh Barker**

**Education Team Presenter**
■ Having achieved a Master's in physics and astrophysics, Josh continues to pursue his interest in space at the National Space Centre.

**Gemma Lavender**

**Staff writer**
■ Gemma has been elected as a fellow of the Royal Astronomical Society and recently joined the **All About Space** team on a permanent basis.

DEEP SPACE

# What would Hubble see from distant galaxies?

**Jack Walker**

A lot of other galaxies! The Hubble Space Telescope is often pointed out into deep space, by doing this scientists were able to use information about the most distant objects to calculate the age of the universe.

Some of Hubble's most important images are called the Deep Field series. These images were taken by the telescope looking deeper into space than had ever been done before. By doing this it was hoped we could unlock more of the secrets of the universe. Information gained from these images includes the age of the universe, the rate at which it is expanding and even an estimate for the number of stars in the universe. As well as answering the big questions, Hubble has helped us to understand the formation of stars and galaxies among other things. **JB**

Hubble's Deep Field images have allowed us to look deeper into space than ever before

**Make contact:** @spaceanswers /AllAboutSpaceMagazine questions@spaceanswers.com

SOLAR SYSTEM

# Which planet in our Solar System is most hostile?

Venus – as shown in this computer-simulated view using data from the spacecraft Magellan – has an unbearably hot average temperature of 462°C (864°F)

**Glen Smith**

Thanks to its thick atmosphere, which consists primarily of carbon dioxide, Venus has some of the worst weather in the Solar System and would be an extremely unpleasant place to find yourself. A runaway greenhouse effect makes it the hottest planet in our Solar System, with an average surface temperature of 462 degrees Celsius (864 degrees Fahrenheit), hotter than Mercury, even though Mercury is closer to the Sun. The temperature is not the only thing you have to worry about, though, as the atmosphere also provides a crushing pressure on Venus's surface which is about 90 times what we experience on Earth. Clouds, made up of sulphuric acid, line the skies and are responsible for frequent, intense lightning storms. **ZB**

DEEP SPACE

# Do green stars exist?

**Paul Davies**

Technically, there are stars that are green. That is, they emit their peak radiation at a wavelength that our eyes define as green. However, you'll never see a green star and here's why.

Stars emit radiation over a broad range of wavelengths and the human eye is most sensitive to yellow and green radiation. When a star is green, you'll find that it is throwing out light that's right in the middle of the visible spectrum. This means that it is radiating strongly at all visible wavelengths and most of this radiation can be found right in the middle. So, when we look at one of these particular stars, all colours are mixed and you're left with the colour white. This means that you'll never ever see a green-looking star through a telescope. **GL**

Green stars do not exist to the human eye

ASTRONOMY

# Can any telescope be used for solar observing?

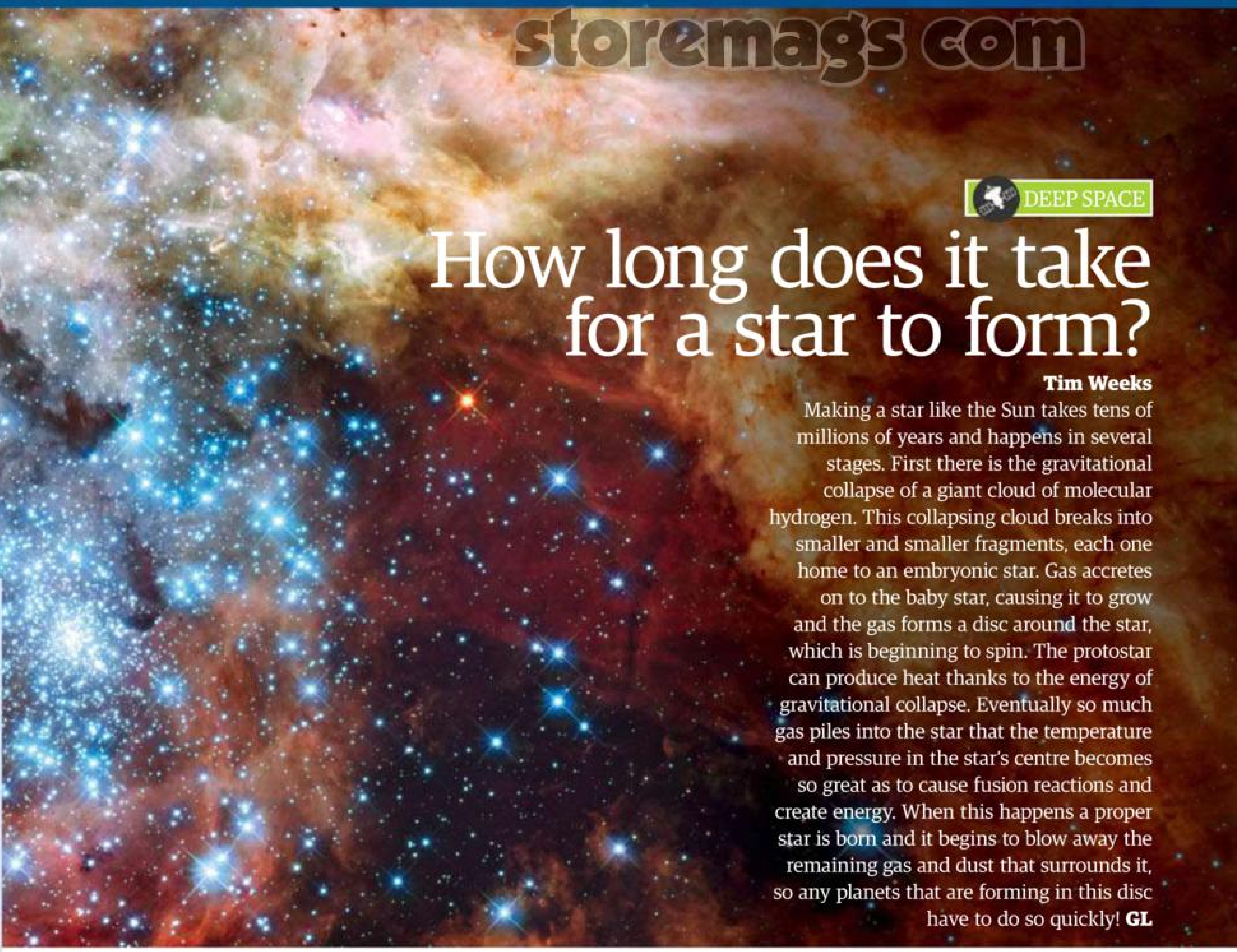
**David Cooper**

With the correct filters and safety checks almost any telescope can be used to look at the Sun, however, the proper precautions must be taken if you intend to embark on a solar-observing session.

It should go without saying that the Sun is bright and that looking directly at our star can cause permanent eye damage or even blindness. This danger becomes even more apparent when you are focusing the light from the Sun using lenses.

If you do not want to splash out on a dedicated solar telescope or expensive filters for your telescope then you can project the image from your telescope on to white paper. Alternatively, you can purchase special hydrogen alpha solar filters which filter out most of the wavelengths of light, allowing you to concentrate on those wavelengths associated with hydrogen and, therefore, most interesting to solar observers. **SA**

If you do not want to pay out for a dedicated solar telescope (pictured here), you can use any telescope to project the Sun's image on to white paper



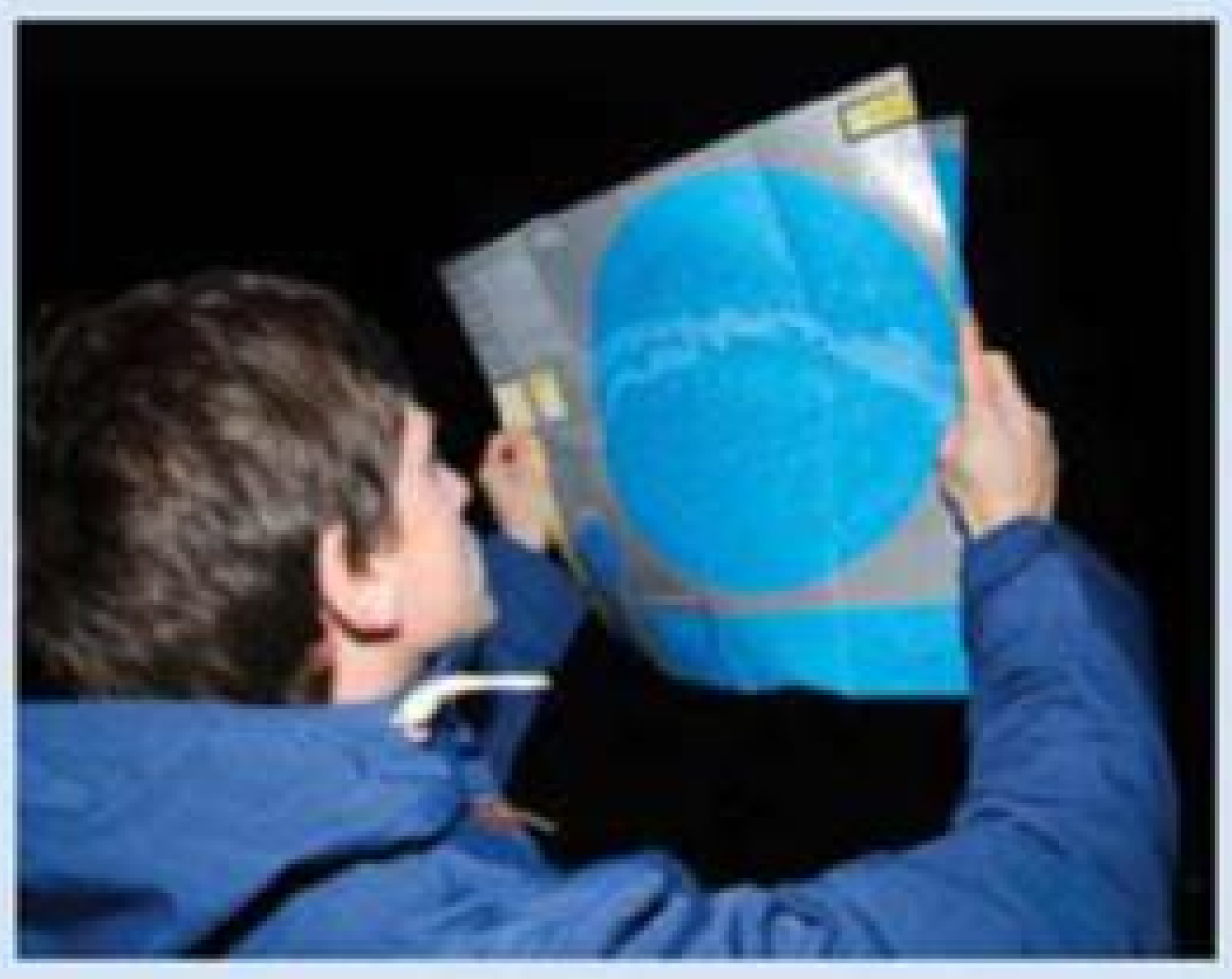
Stars are born during the gravitational collapse of a massive cloud of molecular hydrogen

DEEP SPACE

# How long does it take for a star to form?

**Tim Weeks**

Making a star like the Sun takes tens of millions of years and happens in several stages. First there is the gravitational collapse of a giant cloud of molecular hydrogen. This collapsing cloud breaks into smaller and smaller fragments, each one home to an embryonic star. Gas accretes on to the baby star, causing it to grow and the gas forms a disc around the star, which is beginning to spin. The protostar can produce heat thanks to the energy of gravitational collapse. Eventually so much gas piles into the star that the temperature and pressure in the star's centre becomes so great as to cause fusion reactions and create energy. When this happens a proper star is born and it begins to blow away the remaining gas and dust that surrounds it, so any planets that are forming in this disc have to do so quickly! **GL**



There are 46 constellations in the northern sky, while 29 can be found in the southern hemisphere. The other 13 lie across the ecliptic plane

ASTRONOMY

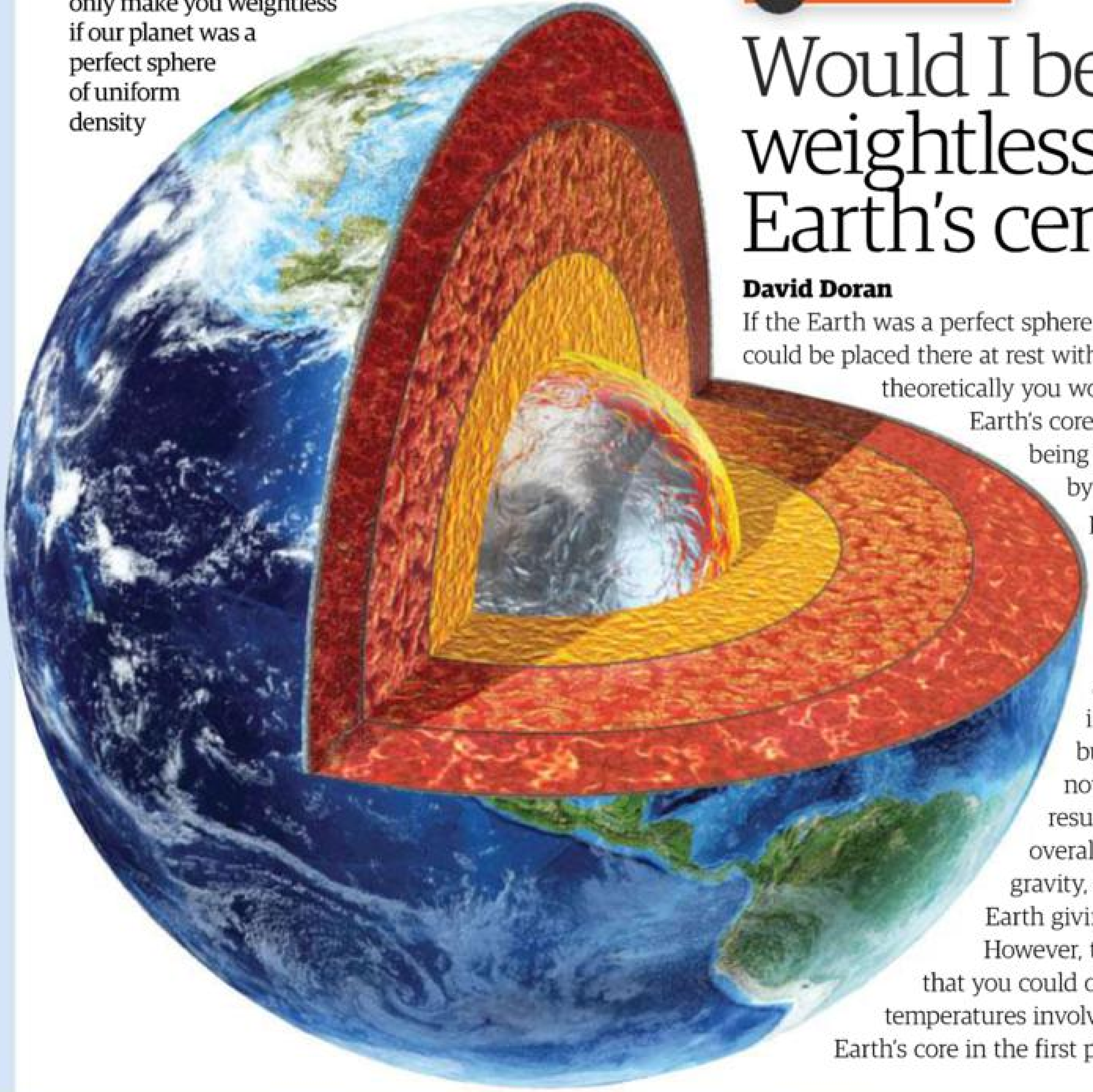
# Are the constellations the same in both hemispheres?

**Alison Watson**

Constellations are patterns drawn using the stars, with the official count standing at 88 split more or less evenly between the northern and southern hemisphere.

The first constellations were drawn thousands of years ago; in fact, research shows that every major civilisation had a set of constellations drawn out of the stars they could see throughout the year. This has resulted in hundreds of different patterns, many overlapping with others.

In the modern era we use a set of 88 clearly defined patterns. 48 of these are ancient constellations, listed by Ptolemy as far back as 150 CE. Your latitude on the Earth determines which constellations you are able to see. **JB**



Travelling to the Earth's core would only make you weightless if our planet was a perfect sphere of uniform density

SOLAR SYSTEM

# Would I be weightless at the Earth's centre?

**David Doran**

If the Earth was a perfect sphere of uniform density, and you could be placed there at rest with no overall movement, then theoretically you would be weightless at the Earth's core. This is because you would be being pulled equally in all directions by the mass of the (uniform) planet, giving an overall gravitational force of zero. And with no overall gravity force, there is no weight.

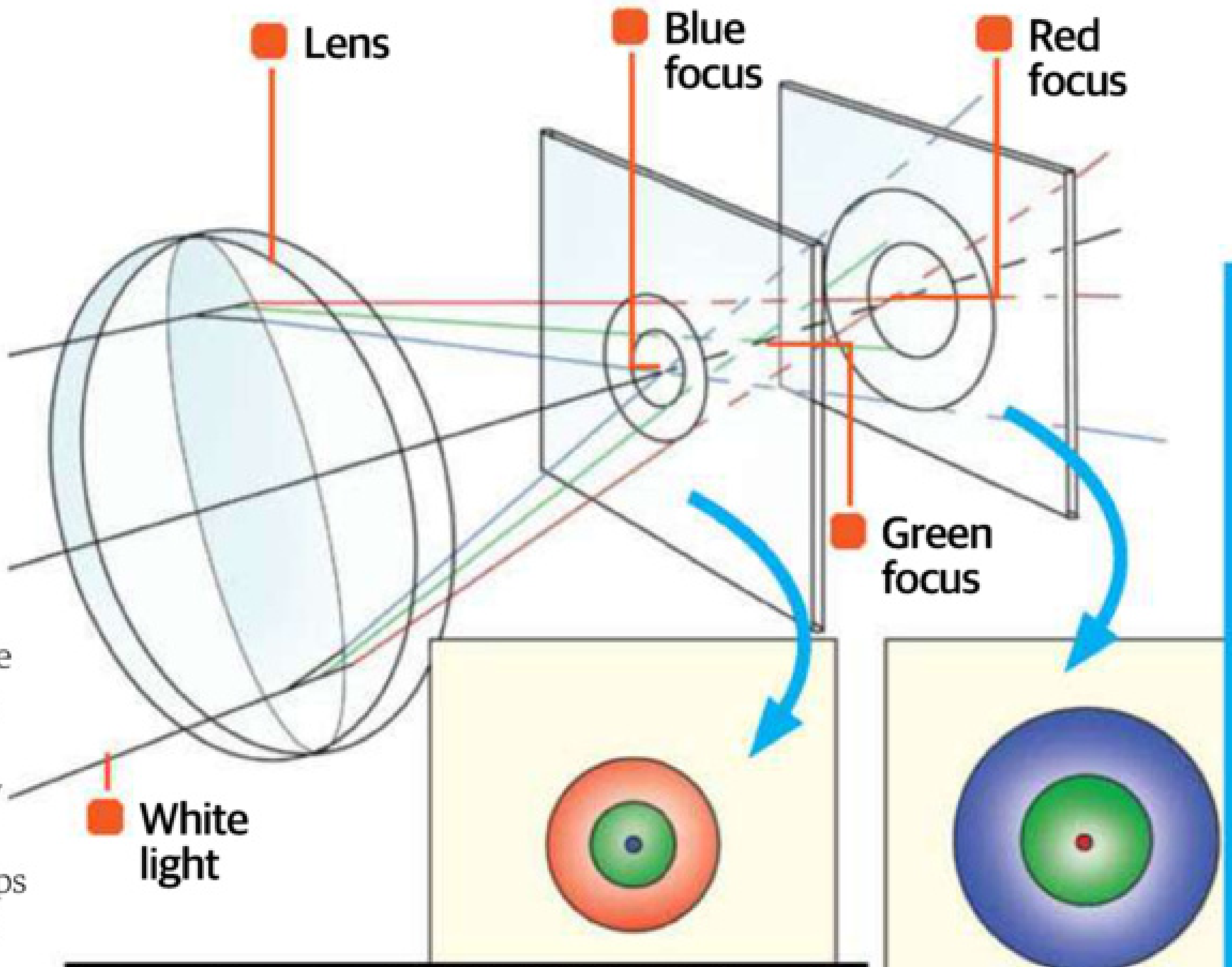
However, our planet is not a perfect sphere. Instead it is squashed at the poles and bulges at the centre. It is also not of uniform density. As a result, you would eventually feel an overall pull due to a denser region of gravity, and the thicker 'bulge' of the Earth giving you a small effective weight. However, this does of course assume that you could overcome the extreme temperatures involved with travelling to the Earth's core in the first place! **SA**

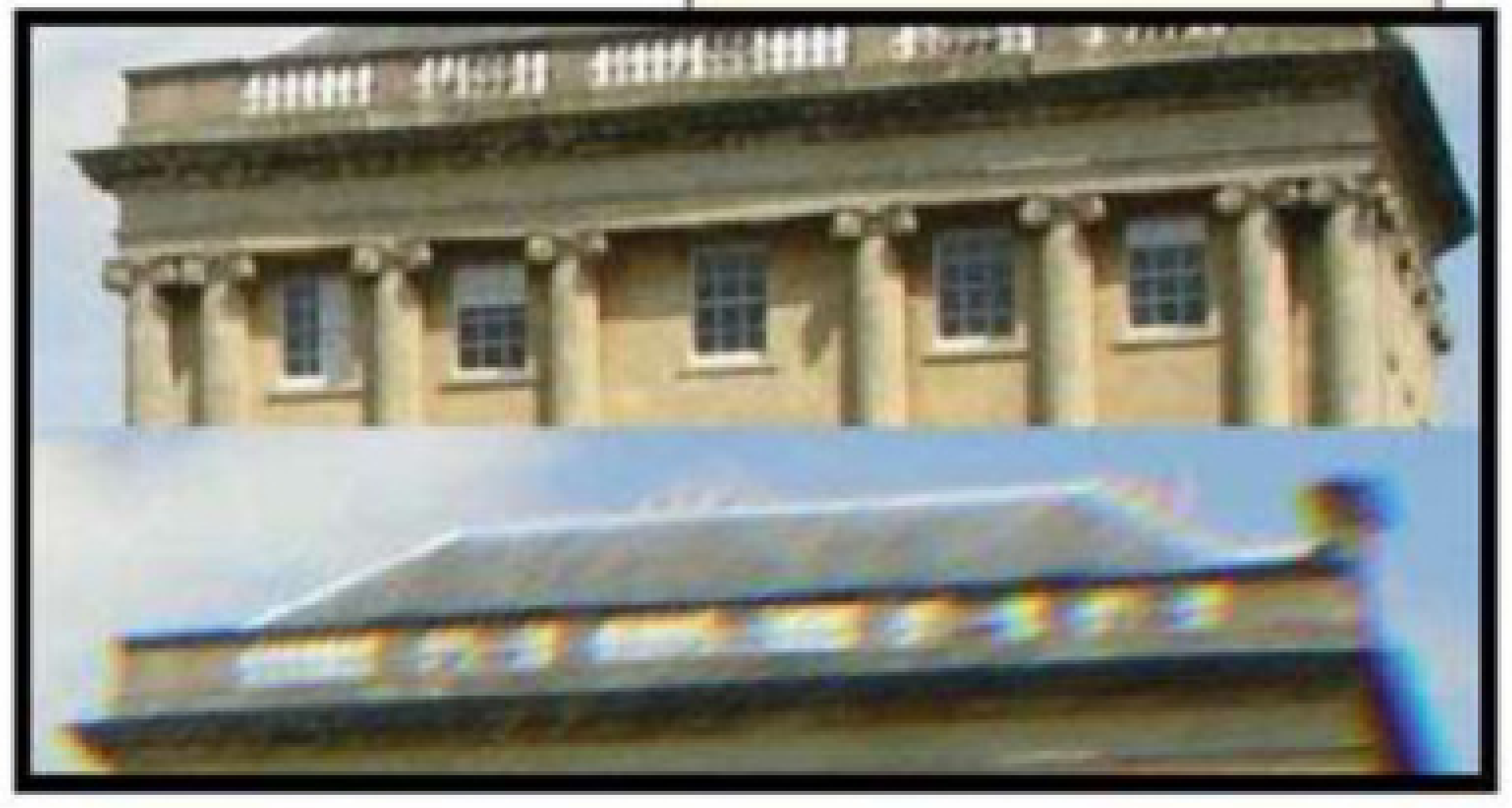
ASTRONOMY

## What is chromatic aberration?

**John Beckingham**

Chromatic aberration is a colour distortion that occurs when a telescope lens fails to focus all the different colours to exactly the same focal point. This is because different colours have different wavelengths and hence come to focus at slightly different locations because of the different refractive index for different wavelengths, perhaps a fraction misaligned with the other colours but enough to create 'colour fringing' in the image seen through the telescope. Chromatic aberration is a problem for refracting telescopes, which use lenses. One way to fix it is to have a doublet lens with two sections made of crown and flint glass, which are able to compensate for the differing refractive indices. Such telescopes are called apochromats. Another way is to use specially treated glass, such as glass containing fluorite that lowers the optical dispersion of the light. **GL**




An example of 'colour fringing' which is caused by chromatic aberration can be seen in the bottom image on the left

SPACE EXPLORATION

## Why should we explore the Moon?

**Keith Barnes**

Studying the Moon provides a unique method for learning about the history of the Earth and the formation of the Solar System. The Moon and Earth were both formed during the creation of our Solar System, approximately 4.6 billion years ago. In contrast to the Earth, whose surface is constantly recycled due to plate tectonics, the surface of our Moon has remained relatively unchanged ever since this time. Studying the Moon allows us to further understand our celestial neighbour, but also helps us to unravel processes that the young Earth may have experienced in the early Solar System. **ZB**

Studying the Moon should help us learn more about the formation of our own planet

Missions such as GRAIL have helped us to learn more about the Moon – in particular, its interior structure

## Quick-fire questions

@spaceanswers

### Are new stars still being formed in our galaxy?

Yes. On average the Milky Way galaxy forms around ten new stars each year in places like the famous Orion Nebula, which you can see as a fuzzy object on winter nights in Orion.

### Why don't supermassive black holes suck in the stars of their galaxy?

What you have to remember is that black holes do not 'suck' things in – instead they have a gravitational field just like other objects and, as a result, stars can orbit around them like planets orbit the Sun. A black hole is only bad news for a star if it gets so close that the gravity overrides its motion and drags it in.

### How big a telescope would you need to view Gliese 581 g in detail?

No current telescope is big enough to see Gliese 581 g. The 39-metre (128-foot) European Extremely Large Telescope, being built this decade, might be able to have a go, however.

### Why is Uranus on its side?

It is thought that a large protoplanet smashed into Uranus billions of years ago, sending the planet tumbling. It's now tilted at an angle of 98 degrees, orbiting the Sun like a rolling ball.

### What is a Wolf-Rayet star?

Stars of more than 20 times the mass of the Sun use all of their hydrogen fuel, swelling up to become red supergiants. A truly massive star will make the final transition to a Wolf-Rayet; stars that blast out huge amounts of stellar material.

### Which planet has the most moons?

As of 2013, gas giant Jupiter has the most confirmed moons with a total of 67. Its most visible moons from Earth are Io, Europa, Ganymede and Callisto.

# Quick-fire questions

@spaceanswers

**How can I listen to the cosmic microwave background (CMB)?**

If you have an old analogue television set, tune it into static. About one per cent of the 'snow' on your screen is from the cosmic microwave background.

**Will stars ever stop forming?**

Yes, although it is not clear how long that will be. There is still plenty of hydrogen gas left in the universe to form stars for many billions of years to come, but the peak of star formation was about 11 billion years ago and it has been slowing ever since then.

**What is the fate of our universe?**

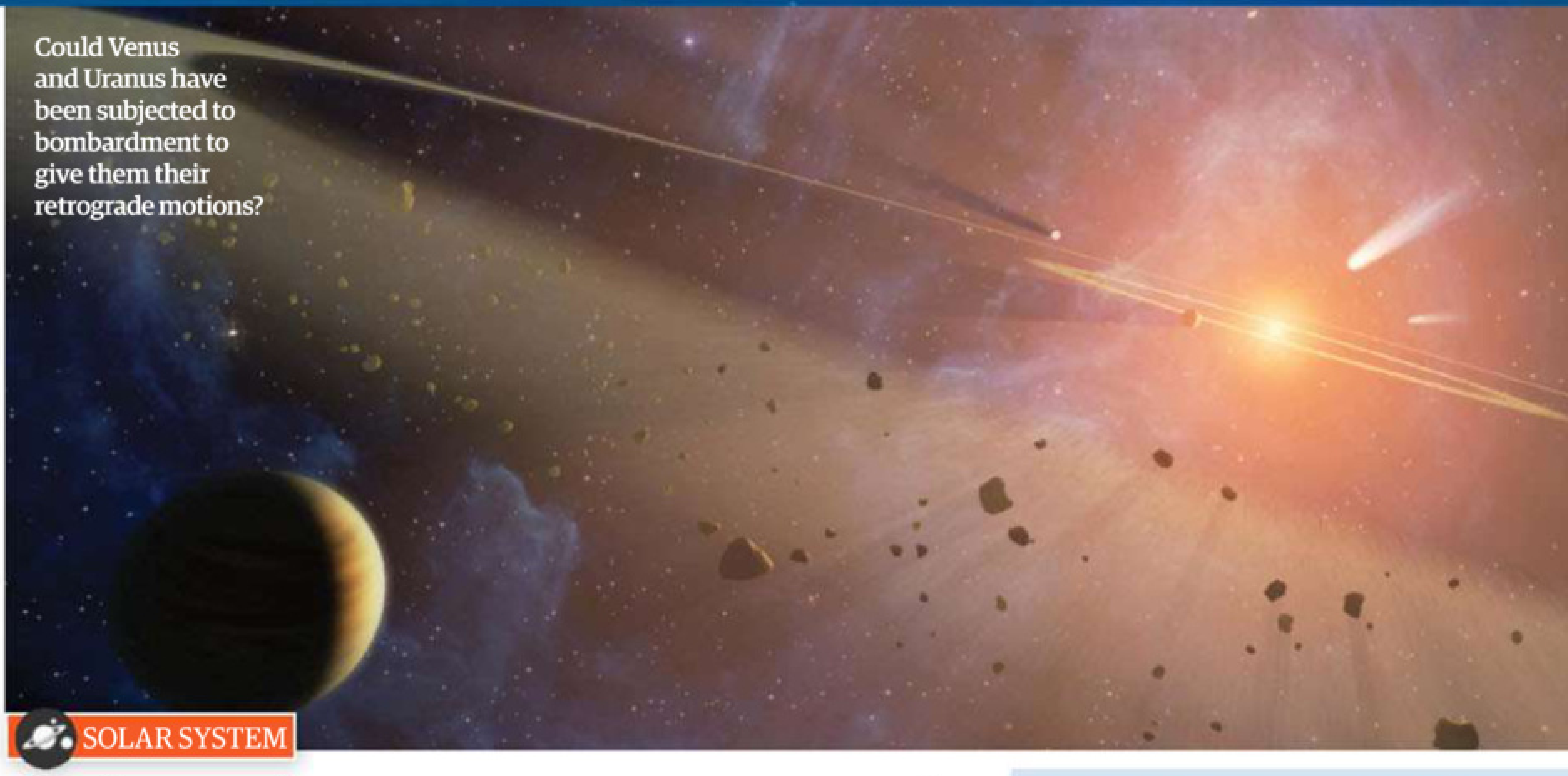
This is uncertain. Dark energy is currently causing the expansion of the universe to accelerate, but not enough for a 'Big Rip'. The current fate theory is of an ever-expanding universe gradually getting darker and colder as the galaxies recede out of sight and the stars go out one by one.

**What's the difference between the Kuiper belt and the Oort cloud?**

The Kuiper belt is a disc-shaped region, similar to an icy asteroid belt, that lies between the orbit of Neptune at about 30 times the distance of Earth from the Sun and about 50 times that distance. The Oort cloud is a spherical cloud of icy comets even further out, around 50,000 times the distance of Earth from the Sun.

**Has our galaxy ever collided with another?**

Our galaxy has experienced so-called minor mergers with dwarf satellites, cannibalising their stars. It is colliding with the Sagittarius dwarf galaxy right now but it has not experienced a major merger with a big galaxy yet.



Could Venus and Uranus have been subjected to bombardment to give them their retrograde motions?

SOLAR SYSTEM

# Why don't Venus and Uranus spin like the other planets?

**Brian Vaughan**

These are two of the biggest mysteries of the Solar System. During their early lives the inner planets were battered by impacts which could have knocked some of them into backwards, or retrograde, spins so that the Sun would rise in the west and set in the east. Even Earth may have spun backwards before the impact that formed the Moon. So Venus's slow retrograde rotation may be a result of a large, ancient impact. The same could hold true for Uranus, but its story is more complicated because it is also tilted at a 98-degree angle. **GL**

DEEP SPACE

# What is the most puzzling thing about our universe?

**Alison Stone**

What happened before the beginning of the universe is one of the biggest questions we currently face about our universe. The Big Bang theory suggests that all of the matter and energy in the universe expanded from a single point. If this is true, what happened before this expansion? Where did the matter and energy come from? At the moment we just don't know! However, this is just one of a number of enigmas concerning our universe; there are many mysteries that we have yet to unravel. How big our universe is, what it is made from, will it end and are we alone, are just a few puzzling examples. Scientists are trying to devise a unified theory of physics that combines our currently disjointed models which may better equip us to answer some of these questions. **ZB**

What happened before the Big Bang is a puzzle scientists are trying to solve

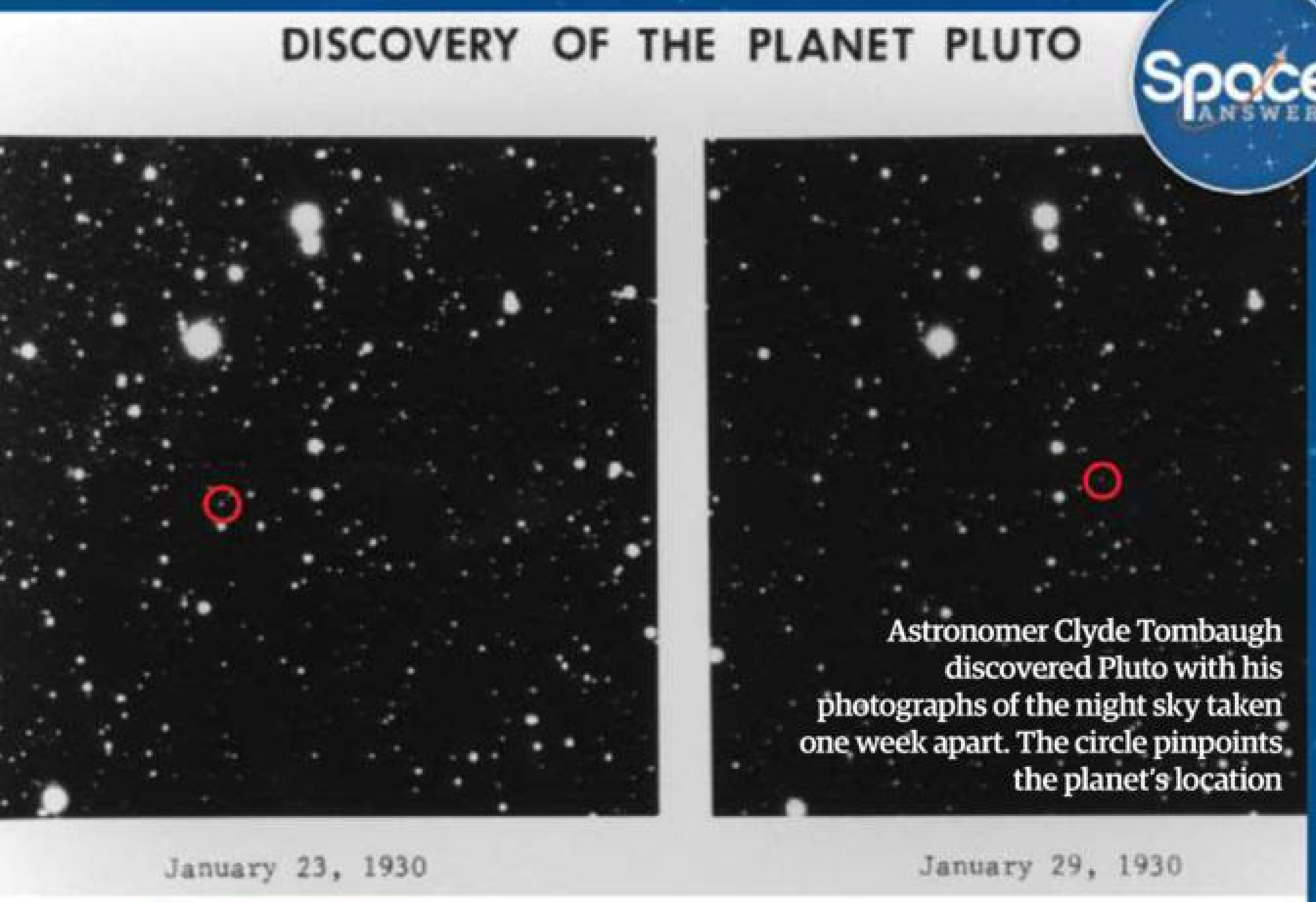
SPACE EXPLORATION

# Is the Kepler Space Telescope broken?

**Jestyn Gray**

Yes, but possibly not beyond repair. Kepler, which is a mission to detect the transits of exoplanets, has been hugely successful so far, discovering over 3,500 candidate exoplanets. It had on board four gyroscopic reaction wheels, which are used for precisely and stably orientating the telescope so that it can perform the sensitive measurements needed to detect the transits. However, two of these wheels have now broken down, hampering Kepler's sensitivity. NASA scientists have, however, come up with a new mission for it that requires less sensitivity, searching for planets around stars on the ecliptic plane. **JB**

**Questions to...** @spaceanswers /AllAboutSpaceMagazine questions@spaceanswers.com



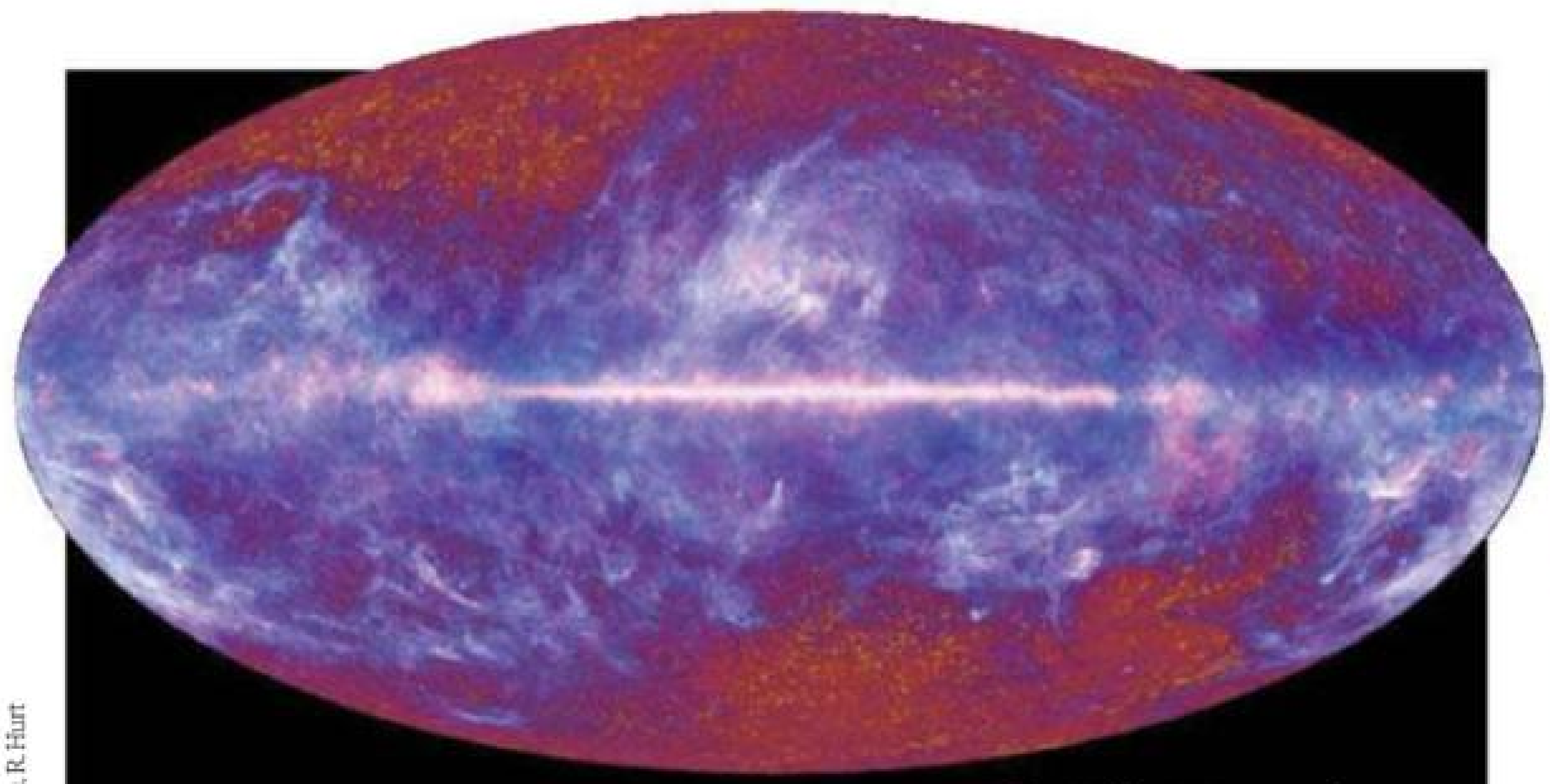
Astronomer Clyde Tombaugh discovered Pluto with his photographs of the night sky taken one week apart. The circle pinpoints the planet's location

ASTRONOMY

## How can I see Pluto?

**Gary Attard**

If you have a telescope in the 10 to 12-inch range then detecting the magnitude +15 light from Pluto shouldn't be a problem, particularly if you have an astronomical camera to hand. The problem is figuring out which object in the field of view is Pluto! Currently Pluto lurks in the dense star-fields of the constellation of Sagittarius, so there are lots of stars around it to confuse it with. Being in Sagittarius means it also doesn't get very high above the horizon during summer, making observation even harder. The best way is to image the region of sky Pluto is in using a CCD or DSLR camera attached to the eyepiece of your telescope over several nights. If you combine all the images, Pluto will appear as the one star that's moving through the field. **GL**



The Milky Way can be seen running across the centre of the Planck all-sky survey

SPACE EXPLORATION

## What's the line in the middle of Planck's full sky map?

**Janine Morris**

The line that is seen running across the Planck sky map is the Milky Way. When observing the universe we often find that there are obstacles.

Ground-based observations have to deal with the weather, the fact that the Earth is moving and even the air around us adds substantial distortion to any stargazing. However, there are a number of ways to get around this, such as adaptive optics and telescope tracking, but the best way is to put the telescope in space. This works very well for observing things within our galaxy but when we turn our gaze further afield, we find that the galaxy gets in the way. Depending on the type of observations being done we can subtract the galaxy data and get an impression of what is behind it, but sometimes it is unavoidable. **JB**

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# Next Issue

## OUR SUPERMASSIVE BLACK HOLE

**Travel to the huge black hole at the core of the Milky Way**

### THE NEXT ISS

Discover the new space exploration platform set to take over from the International Space Station

### 20 AMAZING SPACE ANSWERS

Find out what would happen if you fell into a black hole and more...

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+

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20 BEST STARGAZING SIGHTS ON EARTH

In orbit
**6 Feb 2014**

# STARGAZER

GUIDES AND ADVICE TO GET STARTED IN AMATEUR ASTRONOMY

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# The ultimate guide to the Moon

Key

Naked eye

Telescope

Binoculars

## All About Space takes you on a moonlit tour of our rocky companion

The Moon is by far the most luminous object in the night sky. Reaching a maximum brightness of -12.92 magnitude, it's hard to miss as it boldly takes centre stage and washes out any celestial object that is unable to challenge its brightness.

Its unmistakable entrance is marked by lighting up the sky as a curved sliver of light - the waxing crescent - before revealing its entire face as the full Moon. Despite its beauty, this chunk of rock that has accompanied our planet since its formation is something that many take for granted.

This is because it always seems to be there. We see it on a nightly basis and, with the naked eye, we are able to pick out the craters, volcanoes, ridges and basins that plague its terrain. We suspect that we've seen all that our Moon has to offer. But have we?

If you've never pointed a pair of binoculars or a telescope at our satellite, then you'll be surprised to learn that the Moon is an astronomical object worthy of observing in its own right. What's even better is that because it is the closest celestial body to us it is very easy to observe, even with the naked eye and especially when some of its more obvious features are lit up by the Sun.

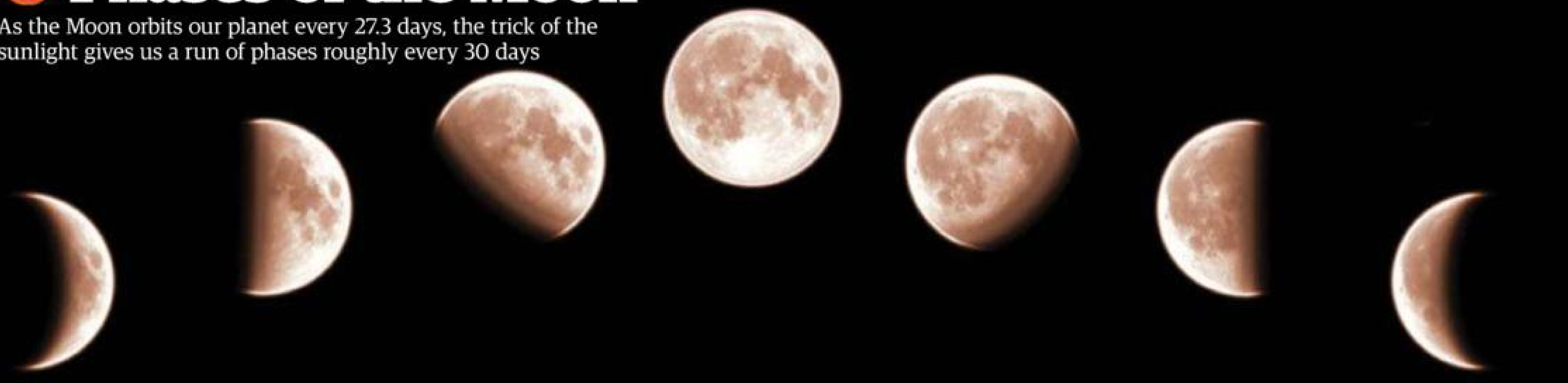
To see the finer details of its battered surface, though, you'll need a pair of binoculars or a telescope; the greater your instrument's aperture, the better. The added beauty of the Moon is that whatever phase it reveals to Earth, it still has several features on show for you to find and observe.

However, there is something that our Moon likes to keep relatively hidden from us - its far side; the face we never see. This is because our rocky companion spins on its axis at around the same time that it takes to orbit the Earth. However, it is not always entirely hidden, sometimes the interaction between the Moon and Earth causes our satellite to rock backwards and forwards in a motion known as libration revealing about nine per cent more of its surface and showing different halves at different times. Because of the angle of the Earth to the Moon, you'd be hard-pressed to spot anything interesting on the Moon's far side, but it is certainly worth looking out for. ■

> "To see its finer details you'll need a telescope or binoculars"

## Phases of the Moon

As the Moon orbits our planet every 27.3 days, the trick of the sunlight gives us a run of phases roughly every 30 days



**Waxing crescent**
Appearing in late afternoon and just after dusk, the Moon begins its visible phases as a waxing crescent.

**First quarter**
Approximately half of the Moon can be seen during its first quarter, appearing in the late afternoon and early evening skies.

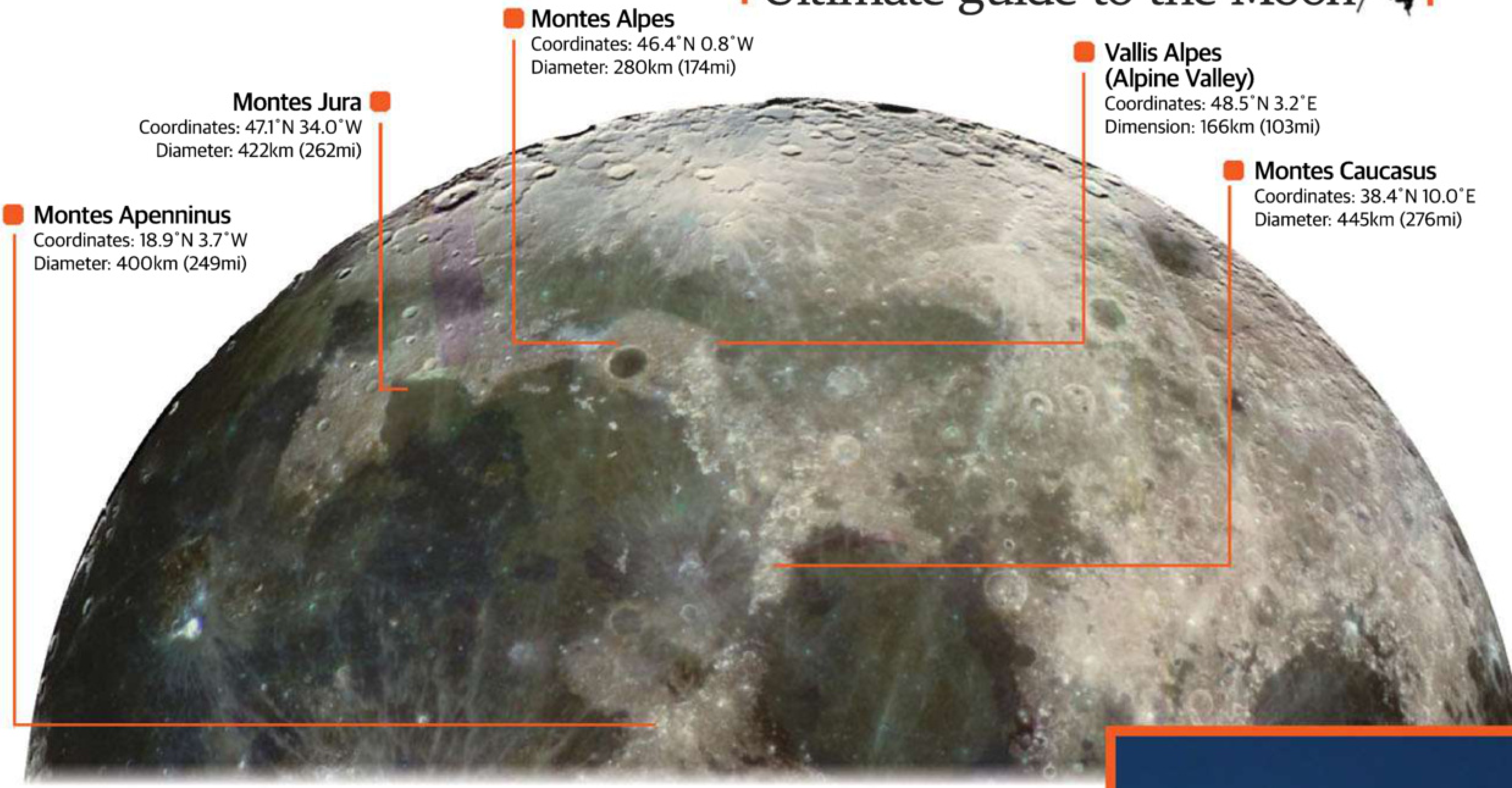
**Waxing gibbous**
Here, the Moon can be seen to have a hunched back, with 51% to 99% of its surface visible.

**Full Moon**
Our satellite in its full glory; the disc is completely illuminated and makes its grand appearance from sunset to sunrise.

**Waning gibbous**
Our satellite starts to step back into the darkness. This phase is visible into the early morning.

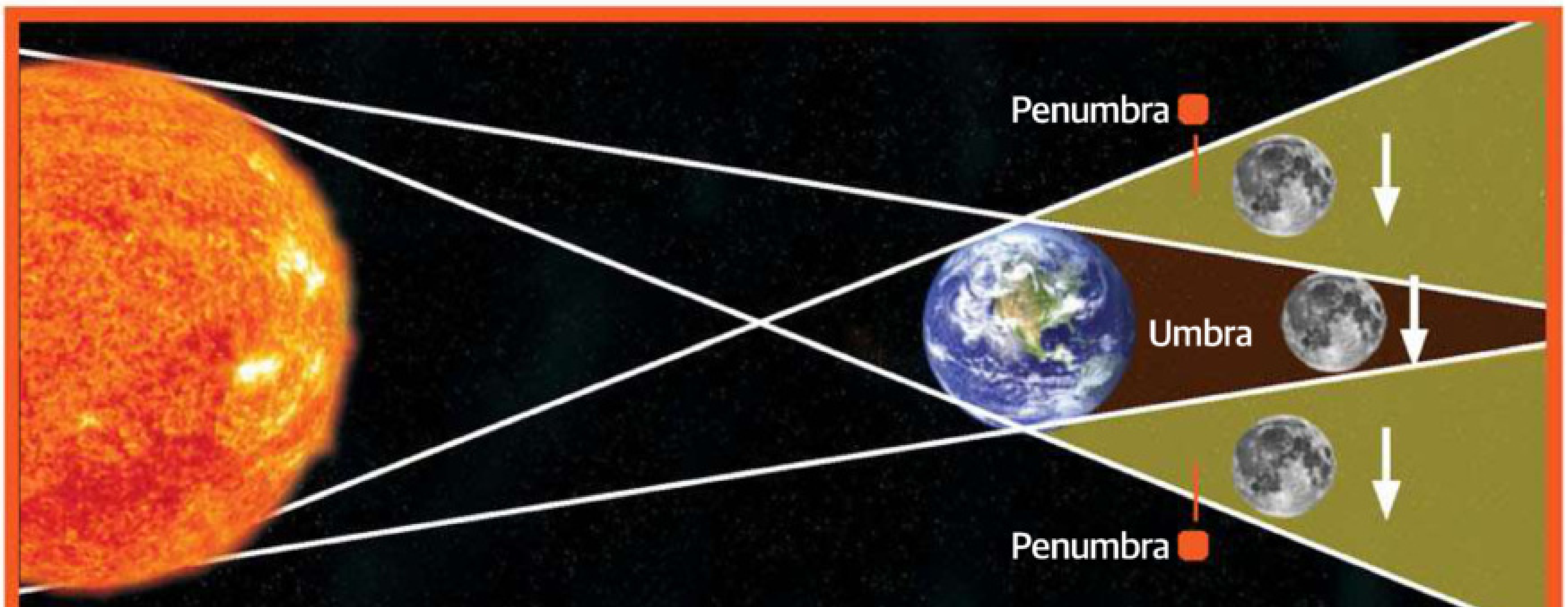
**Last quarter**
You'd have to stay up late into the night and into the morning to catch the last, or third, quarter of the Moon.

**Waning crescent**
The diminishing Moon's last visible phase can be caught in the pre-dawn and early morning sky.



# The mountainous Moon

The lunar surface would not be complete without its ridges, valleys and faults. It also would not be the rocky world we have come to know without the majestic mountains that rise out of its dry, dusty surface and team up to form gigantic mountain ranges stretching out anywhere from 50 to 790 kilometres (31 to 491 miles) in diameter. Despite their monstrous sizes though, you will need a telescope to get the full benefit of spotting these incredible landmarks. In our image above, we've targeted the many mountain ranges and valleys that can be found around the border of the lunar sea, Mare Imbrium. However, there are many other mountains and ranges all over the Moon waiting to be picked up by your telescope. These are best viewed while the Moon is in a transitional phase with its terminator visible.



## In Earth's shadow: lunar eclipses

When the Moon turns crimson, we know that our lunar companion has passed into Earth's shadow - the umbra - where no direct sunlight, other than that which filters through our planet's atmosphere, can reach its surface. When this happens, we are experiencing a lunar eclipse. Unlike solar eclipses, the beauty of the lunar version is that, provided you're on the night side of the Earth, you'll get to see this event wherever you are. As an added bonus, you don't need protective eyewear or even optical aids to watch a lunar eclipse whether it's a total or partial one. We will be treated to two lunar eclipses in 2014.

### Total lunar eclipses of 2014

Date: 15 April
Length of eclipse: 01h 18m
Visible from: Australia, the Pacific, North and South America

Date: 8 October
Length of eclipse: 00h 59m
Visible from: Asia, Australia, the Pacific, North America

## Shining in the Earth's light

When the Moon begins its phases for the month as a waxing crescent before it transitions into its first quarter, you might have noticed that you can just about make out the rest of the lunar surface - and some of the seas that dominate its rocky face - even though it is still in shadow. The brightest segment of the Moon visible to us is basking in the scorching hot rays of the Sun, so what is causing the rest of the Moon to glow when it is not due to reveal itself to us yet?

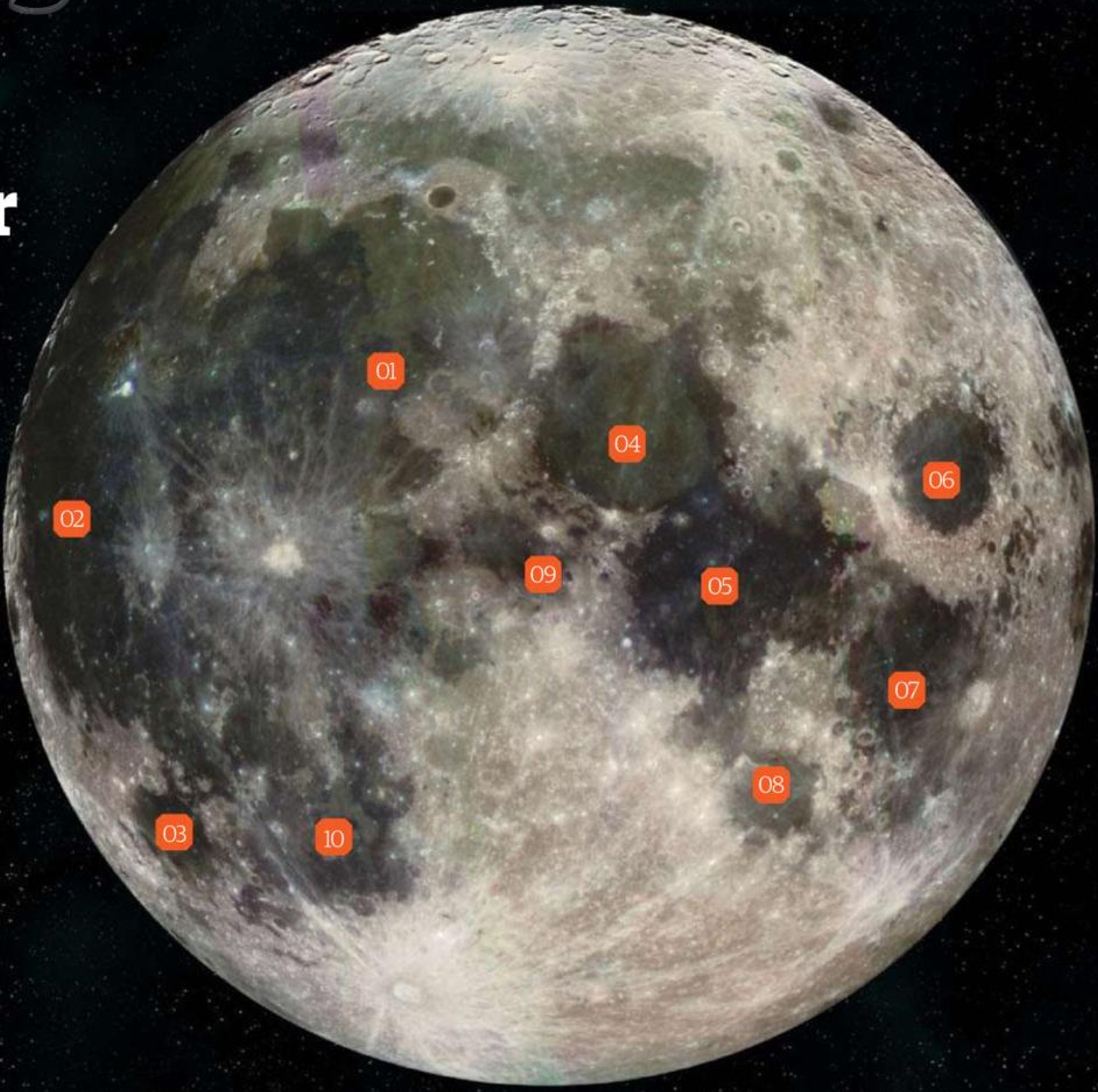
Light rays get wherever they can and what's happening is that the sunlight that's reflected from the Earth is being transferred on to the Moon's face. This is called Earthshine and it is usually most readily observable during the waxing and waning crescent phases.

# Setting sail on the lunar seas

They are the first thing you are likely to spot when you gaze upon the Moon's surface, making that pattern that we often refer to as the Man or Rabbit in the Moon; the Moon's seas or, as astronomers call them, lunar maria.

But unlike our planet, and what early stargazers thought, these are not vast bodies of water that we're used to, these are the plains of our companion's very active past; the mark of volcanic eruptions between some 3 and 3.5 billion years ago that have spewed out lava, rapidly cooling to form stretches of grey basaltic rock. These seas are also fairly dark and less reflective of the Sun's light than the light grey areas that surround them – this is all down to the rich amounts of iron found in these lunar seas.

But it's not all great seas, if you look carefully enough, you can also spot some of the smaller lakes, marshes and bays that litter the lunar surface. Most of these features can be seen when the Moon is full or close to full and with the naked eye. However, if you find that you are struggling, then a good pair of binoculars will help you.



### 1 Mare Imbrium (Sea of Showers)

**Coordinates:** 32.8˚N 15.6˚W
**Diameter:** 1,145km (711mi)
A huge circular sea, Mare Imbrium can be seen immediately to the northeast of the great sea Oceanus Procellarum. Given its size, it can be picked up quite easily by the naked eye.

### 2 Oceanus Procellarum (Ocean of Storms)

**Coordinates:** 18.4˚N 57.4˚W
**Diameter:** 2,500km (1,600mi)
It's not too tricky to spot with the naked eye and is best viewed when the Moon is full or when the Moon makes its morning appearance in the waning or last quarter phase.

### 3 Mare Humorum (Sea of Moisture)

**Coordinates:** 24.4˚S 38.6˚W
**Diameter:** 389km (242mi)
Despite its size, Mare Humorum stands out fairly well in comparison to Mare Nubium. However, optical aids are needed to spot this sea, which is significantly smaller than the Moon's larger mare.

### 4 Mare Serenitatis (Sea of Serenity)

**Coordinates:** 28.0˚N 17.5˚E
**Diameter:** 674km (419mi)
Mare Serenitatis can be found immediately to the east of Mare Imbrium. As with the other lunar seas, the best time to view the Sea of Serenity is when the Moon is full and when conditions are clear.

### 5 Mare Tranquillitatis (Sea of Tranquility)

**Coordinates:** 8.5˚N 31.4˚E
**Diameter:** 873km (542mi)
The closest sea to where Neil Armstrong made the first-ever human footprint on the Moon. Visible during the full, first quarter, waxing gibbous and also the waning phase.

### 6 Mare Crisium (Sea of Crises)

**Coordinates:** 17.0˚N 59.1˚E
**Diameter:** 555km (345mi)
Fairly easy to pick out, Mare Crisium is oval shaped and located to the northeast of Mare Tranquillitatis. It's visible to us on Earth during the first quarter, full and waxing phases of the Moon.

### 7 Mare Fecunditatis (Sea of Fertility)

**Coordinates:** 7.8˚S 51.3˚E
**Diameter:** 840km (520mi)
This region can be tricky to view with the naked eye. A pair of binoculars is recommended for this sea that can be found close to the eastern border of Mare Tranquillitatis.

### 8 Mare Nectaris (Sea of Nectar)

**Coordinates:** 15.2˚S 35.5˚E
**Diameter:** 333km (207mi)
This is difficult to detect with the naked eye but sweep a pair of binoculars from the centre of Mare Tranquillitatis to its southeastern point and you should be able to make out the Mare Nectaris.

### 9 Mare Vaporum (Sea of Vapours)

**Coordinates:** 13.3˚N 3.6˚E
**Diameter:** 245km (152mi)
Close to Mare Serenitatis, this sea might only be just over 240 kilometres (150 miles) across but its dark appearance makes it detectable with the naked eye. It can be found close to the Moon's centre.

### 10 Mare Nubium (Sea of Clouds)

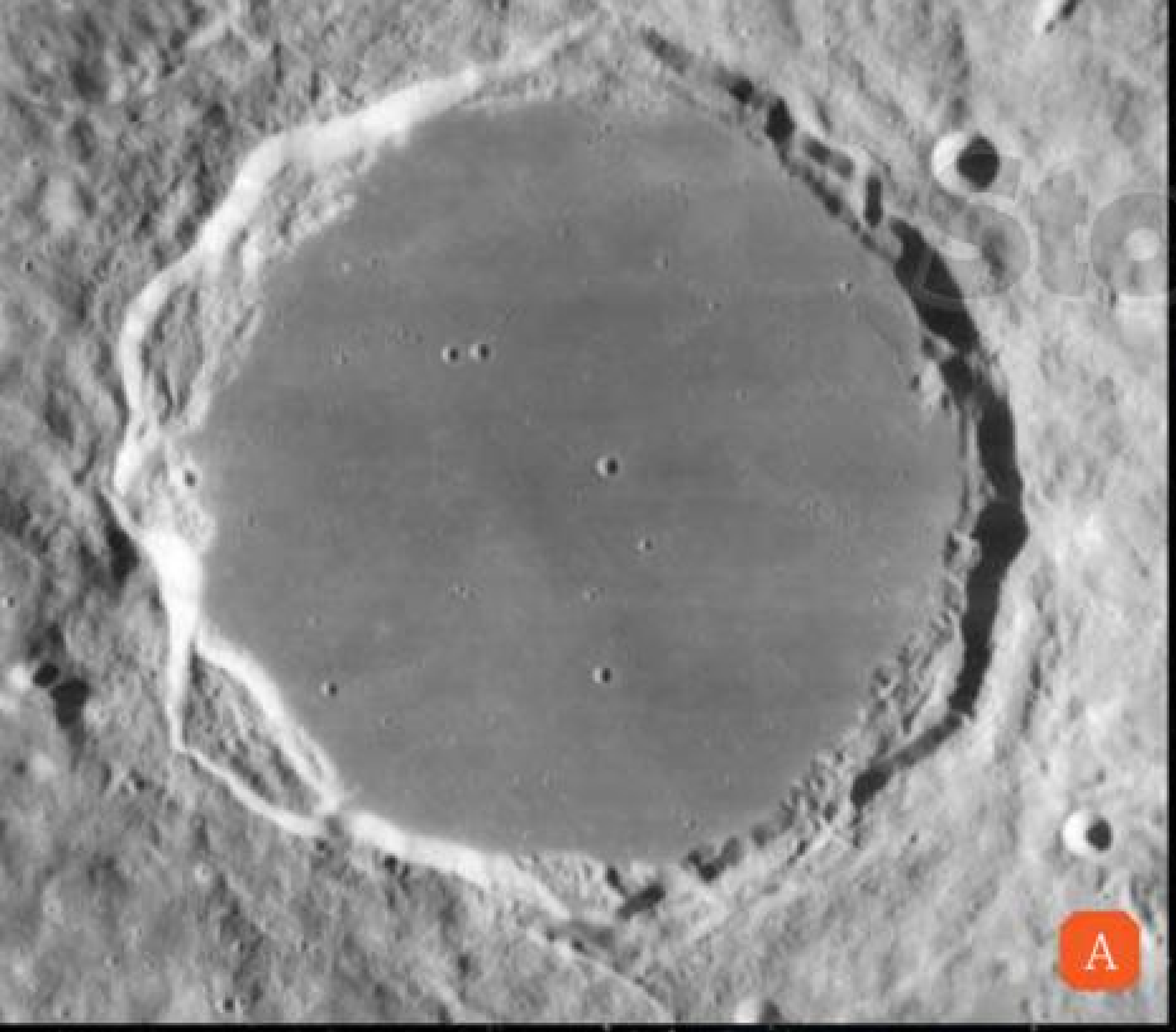
**Coordinates:** 21.3˚S 16.6˚W
**Diameter:** 715km (444mi)
Quite a challenge for the naked eye, Mare Nubium lacks any distinct edges meaning that optical aids are required to pick out this large sea. A good refractor telescope will really bring out its beauty.

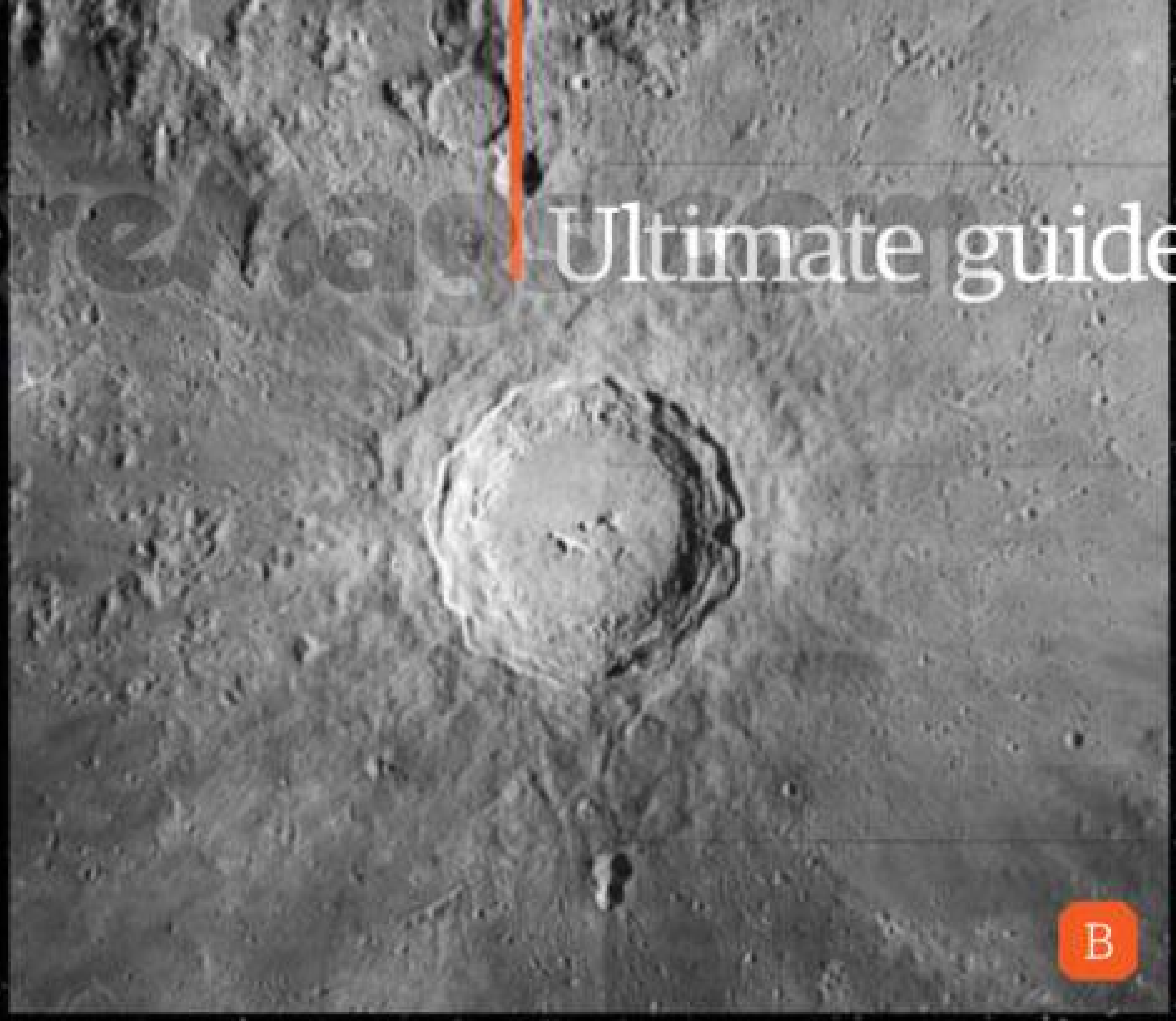
# Counting craters

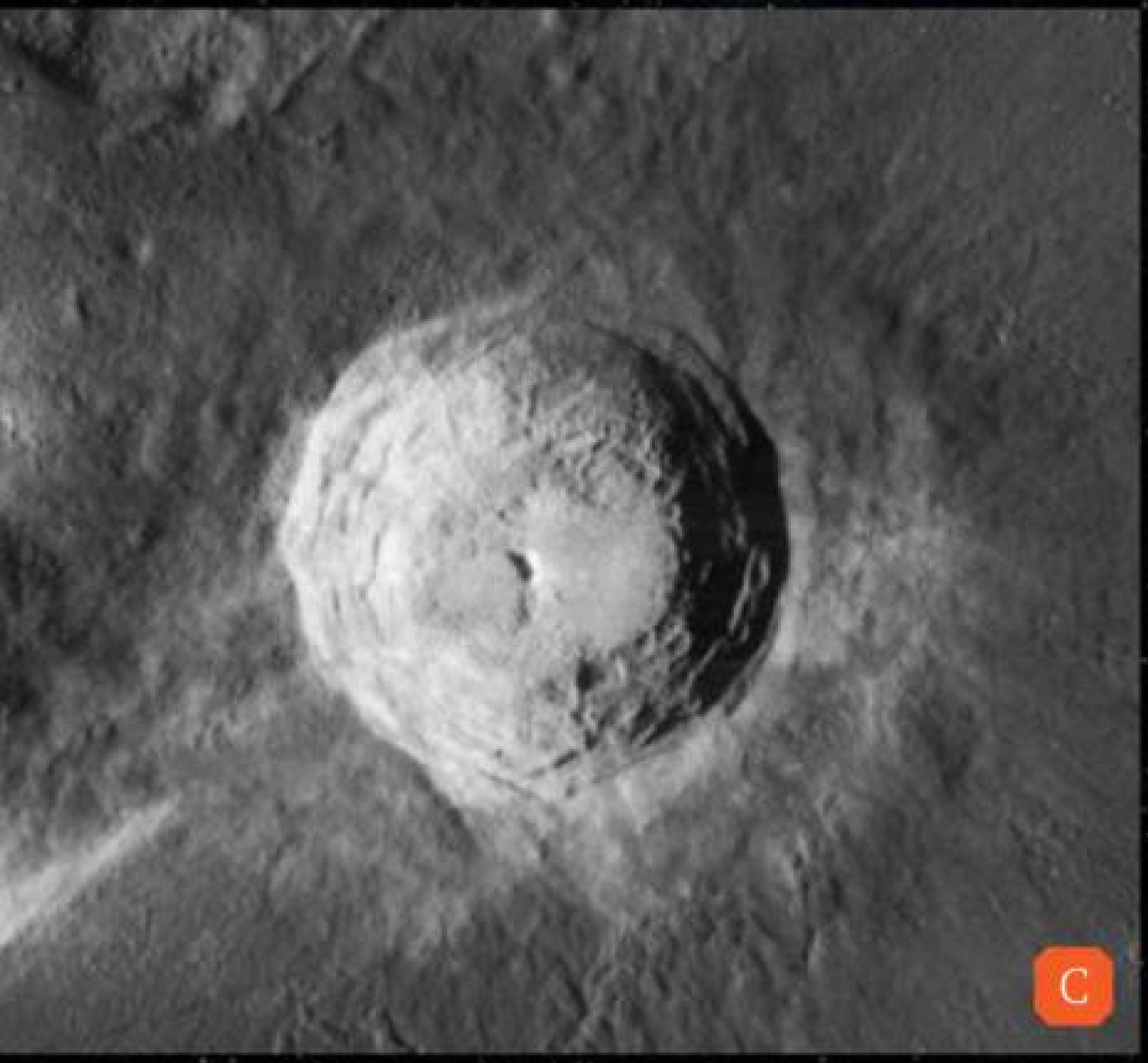
Craters, craters, everywhere! Our Moon shows signs of being incredibly scarred with the thousands of pock marks and dents in its rocky surface - most of which have been formed by chunks of space rock smashing into it.

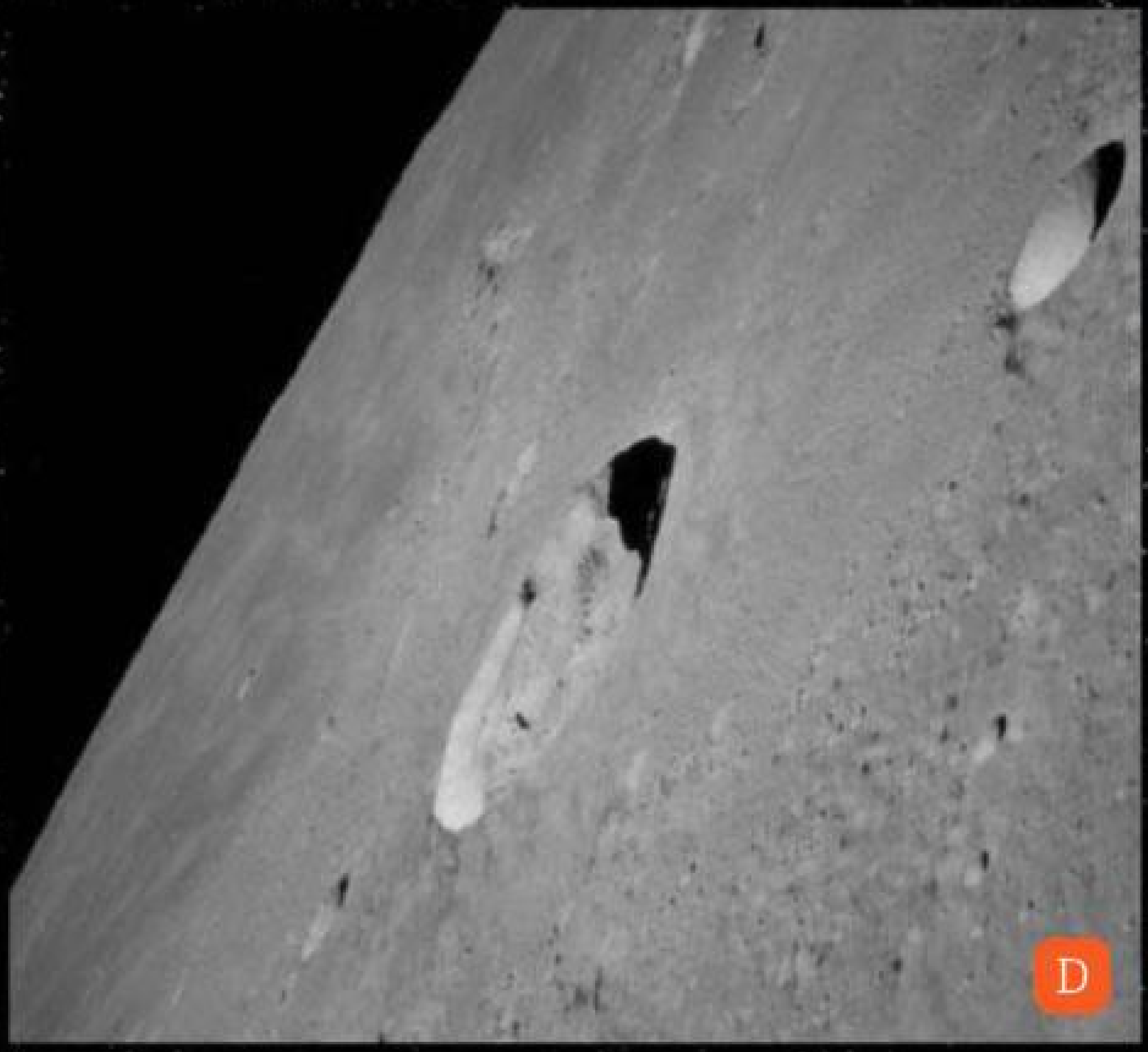
We know the Moon to be a barren world - devoid of any water, atmosphere or tectonic plates. What this means is that there are no elements to wear these craters down and they're there to stay with some dating back over 2 billion years. What's more is that they come in a whole variety of brightnesses, sizes and depths; with some boasting raised rims and central peaks.

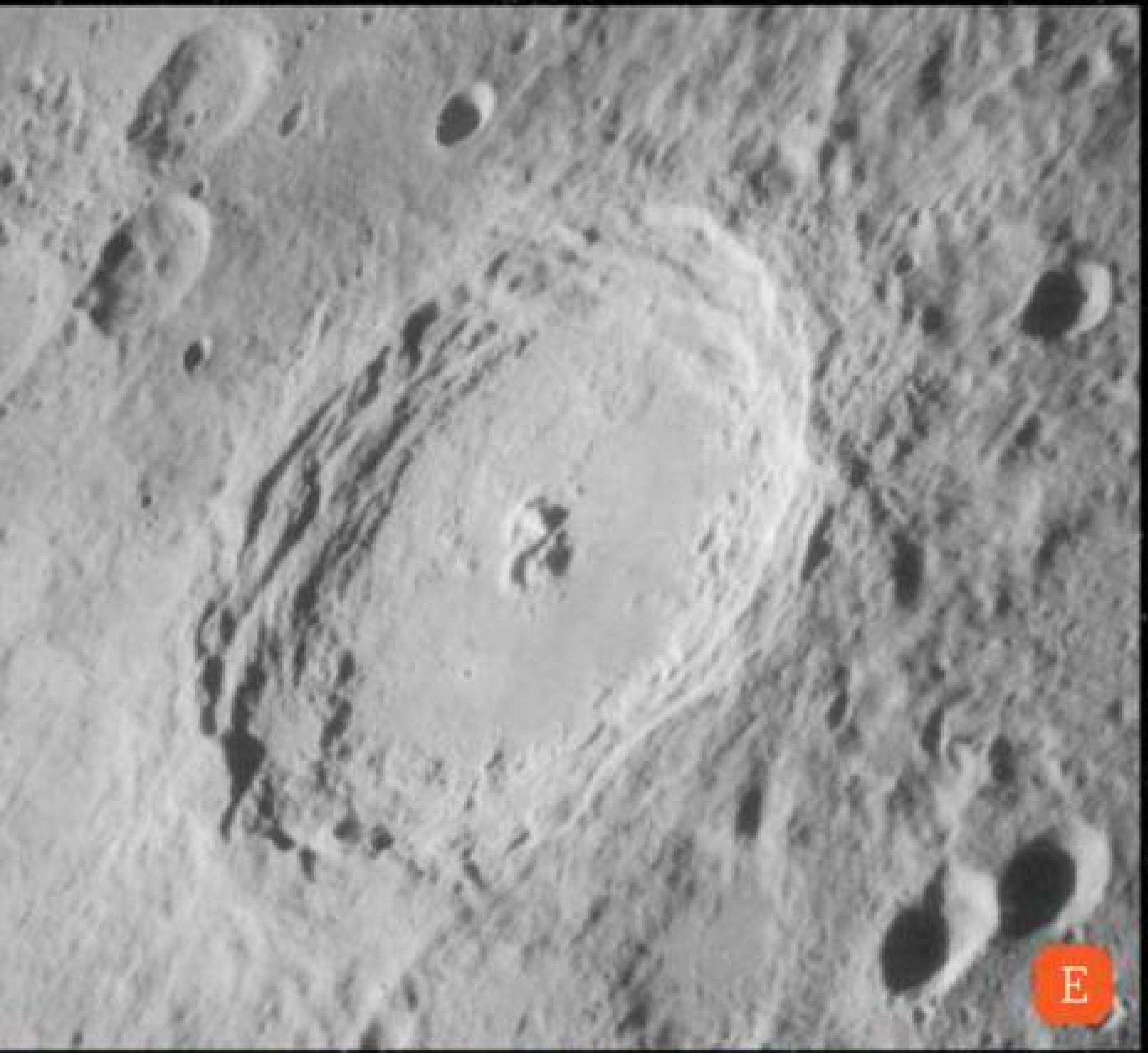
Some of the craters are so big that we can even see them from Earth with binoculars or using a telescope. And, as the Moon shifts through its phases, you can watch the variation in lighting alter their features, making them all the more exciting to watch.

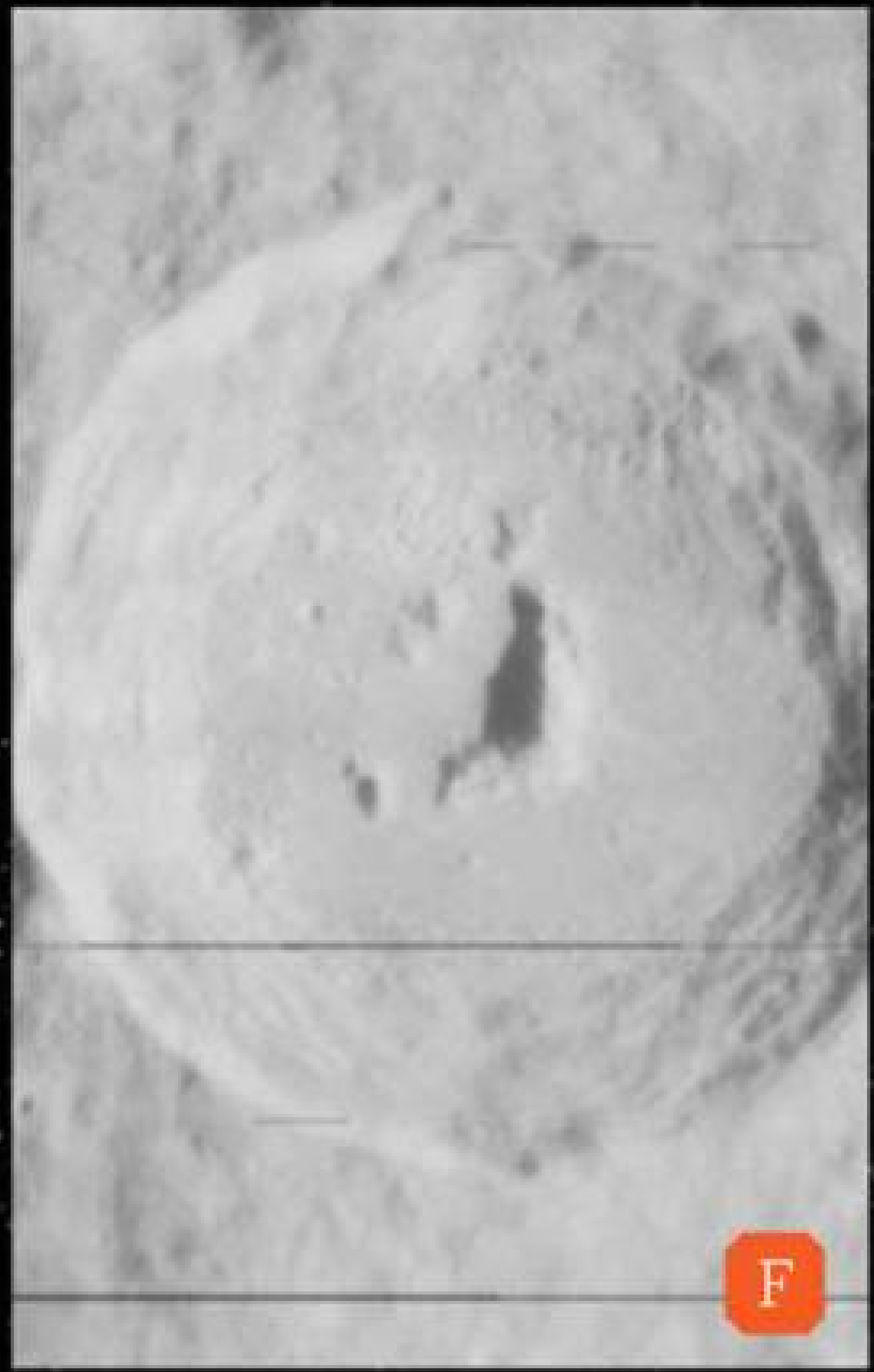


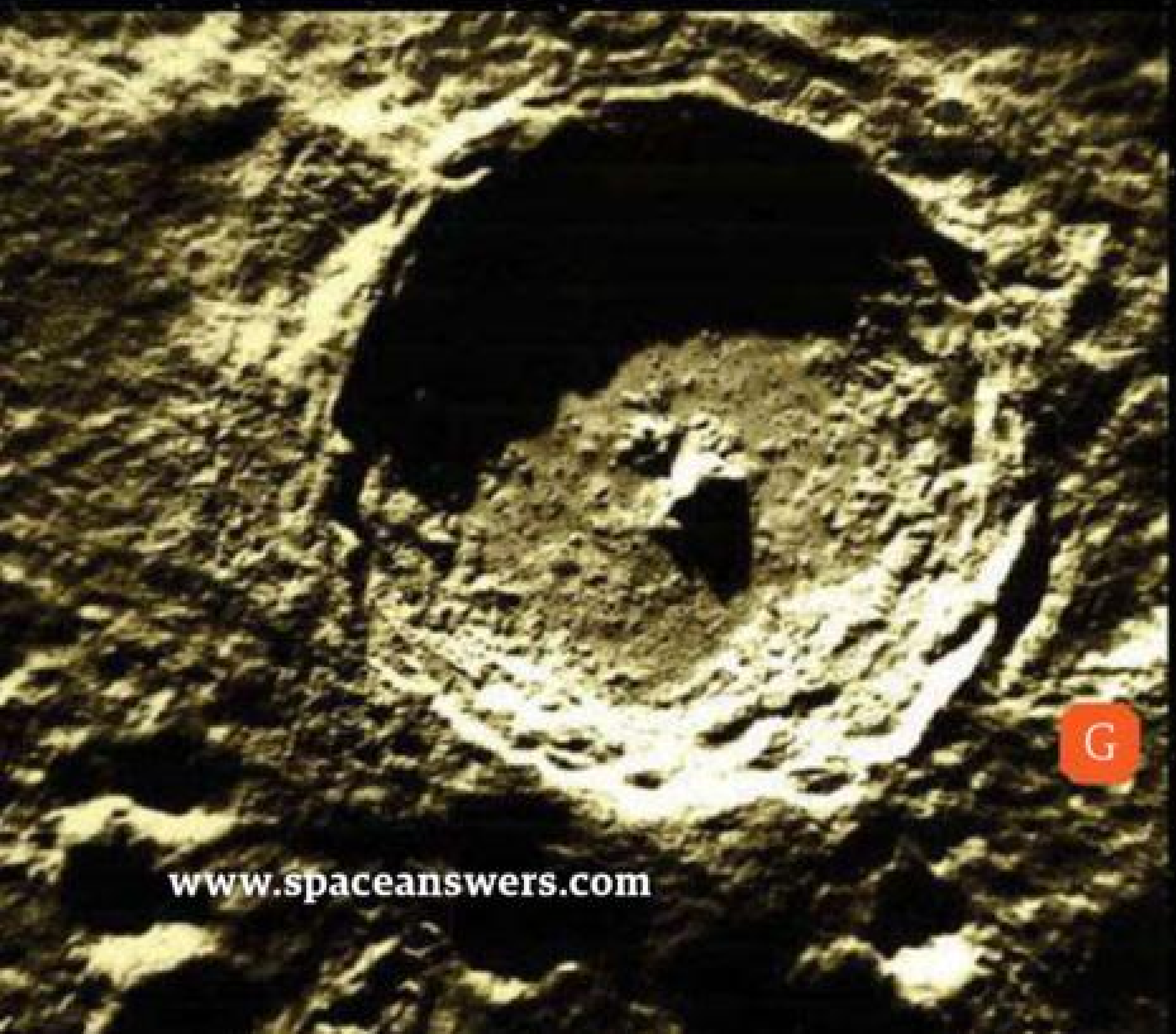


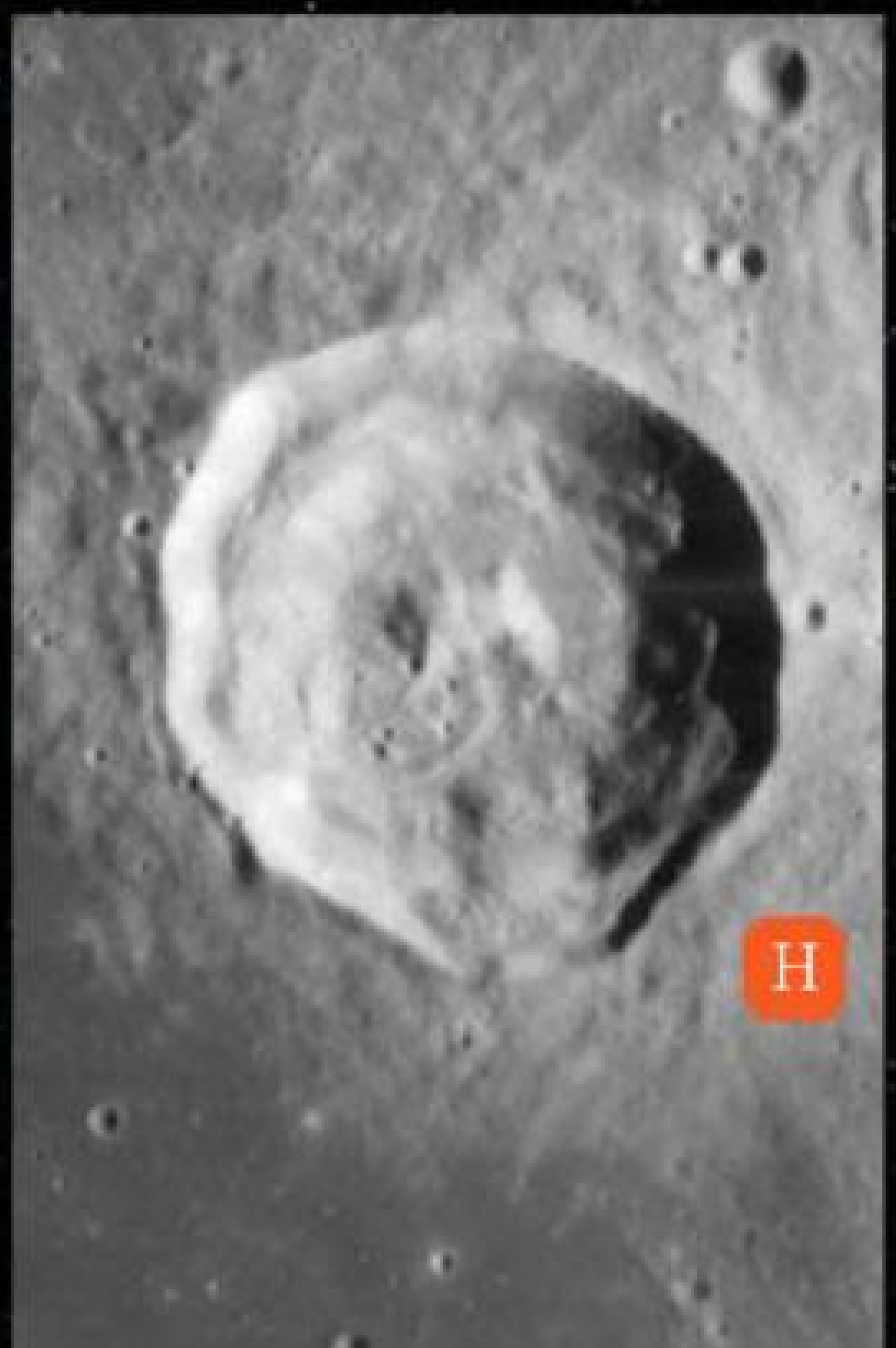












**A Plato**
**Coordinates: 51.6˚N 9.3˚W**
**Diameter: 109km (68mi)**
**Depth: 1km (0.6mi)**

**B Copernicus**
**Coordinates: 9.7˚N 20.0˚W**
**Diameter: 93km (58mi)**
**Depth: 3.8km (2.4mi)**

**C Aristarchus**
**Coordinates: 23.7˚N 47.4˚W**
**Diameter: 40km (25mi)**
**Depth: 3.7km (2.3mi)**

**D Kepler**
**Coordinates: 8.1˚N 38.0˚W**
**Diameter: 32km (20mi)**
**Depth: 2.6km (1.6mi)**

**E Langrenus**
**Coordinates: 8.9˚S 60.9˚W**
**Diameter: 132km (82mi)**
**Depth: 2.7km (1.7mi)**

**F Stevinus**
**Coordinates: 32.5˚S 54.2˚E**
**Diameter: 75km (47mi)**
**Depth: 3km (1.9mi)**

**G Tycho**
**Coordinates: 43.31˚S 11.36˚W**
**Diameter: 86km (54mi)**
**Depth: 4.8km (3mi)**

**H Manilius**
**Coordinates: 14.5˚N 9.1˚E**
**Diameter: 39km (24mi)**
**Depth: 3.1km (2mi)**

©NASA; Alamy.

## Take a longer tour

If you've managed to find all of the features that we've included in our guide and you're feeling ambitious, then you'll be pleased to learn that there's plenty more to uncover on our companion's surface. Head over to the Luna Society's interactive map (www.lunasociety.org/atlas) to continue your tour of the Moon!

# A guide to observing Jupiter and its moons

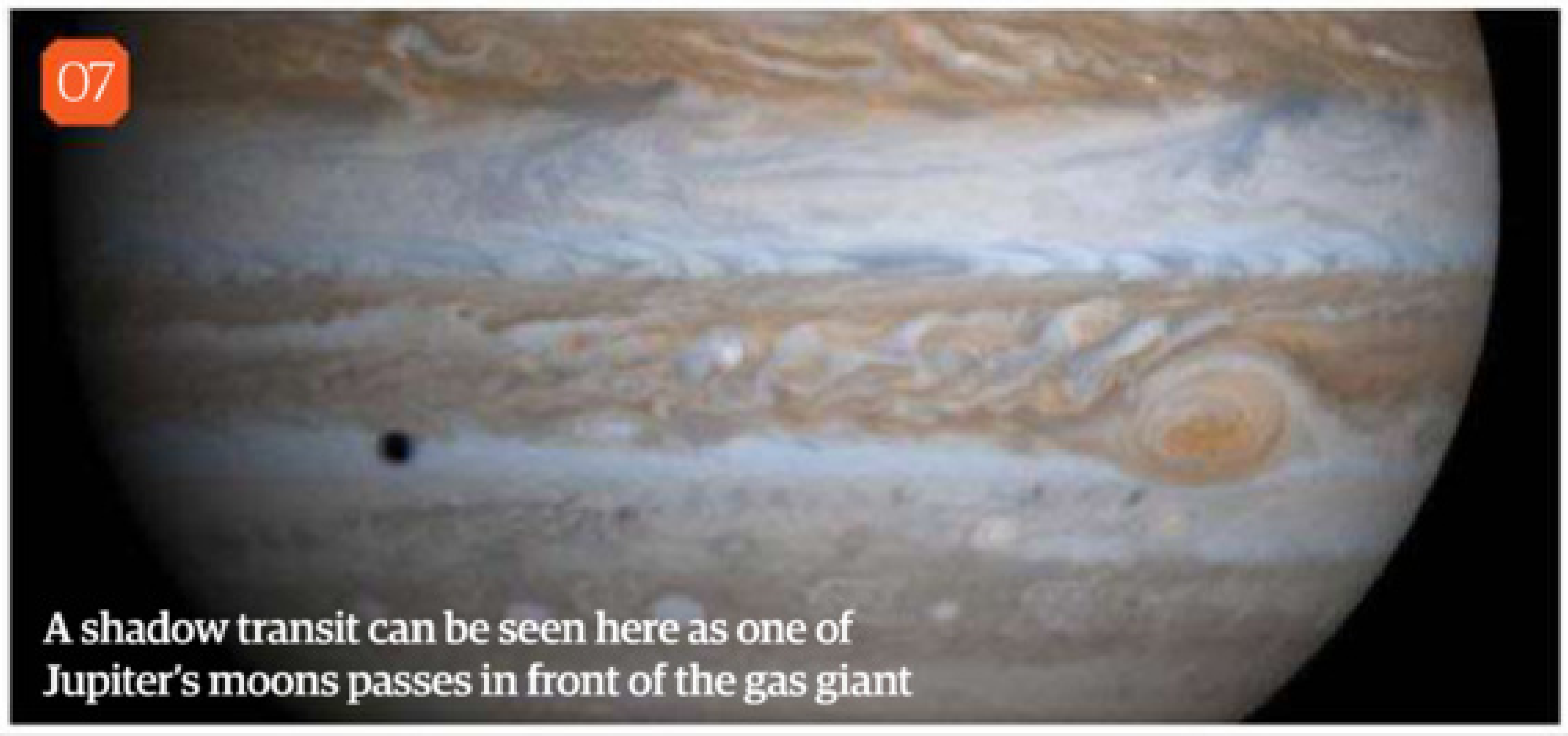
## This guide will take you on a tour of the best and most interesting features to see on the king of the planets

Jupiter is the largest planet in our Solar System and the easiest to observe. You can see it with the naked eye, binoculars or a small telescope. During January 2014 it will be very well placed for observing as it will be at 'opposition' on the fifth of the month. This means that it is directly opposite the Sun in the sky from our point of view here on Earth and therefore will be visible all night.

You can find it nestling among the stars of the constellation of Gemini the Twins and it will be due south at midnight in the early part of the month about halfway between the horizon and the zenith or overhead point. It is bright! It also has a yellowish tinge. A view through binoculars will show a tiny disc with up to four points of light spaced out either side of this disc. These are the Galilean moons of Jupiter - Io, Callisto, Europa and Ganymede. You can watch them change position as they orbit around the giant planet almost on an hourly basis and certainly note the changes of position night by night.

A small telescope will show you a lot more. Magnifications of 50x to 100x will show considerable detail, including some of the cloud belts and possibly the Great Red Spot. Earth's atmospheric conditions will affect what and how much you can see, so be prepared to experiment with more or even less magnification. The use of coloured glass filters can help improve your view, too. They boost the contrast and can allow you to see more detail on the planet surface. A light yellow filter can work well as can an orange or even a red one. It's worth experimenting here too. See if you can see the slightly squashed appearance of the disc. This is caused by the fact that Jupiter is rotating so fast on its axis, in around ten hours, that it is flattened at its poles.

> "During January 2014 gas giant Jupiter will be very well placed for observing"



A shadow transit can be seen here as one of Jupiter's moons passes in front of the gas giant

The moons pass both in front of and behind the disc of the planet, events respectively known as transits and occultations, which can produce fascinating viewing. Transits are the most interesting of all as you may be able to see the shadows of the moons on the disc of the planet itself as the moons cross. These are known as shadow transits.

Don't miss this great opportunity to see this amazing planet.

## Jargon Buster

### Transits and occultations

When one of the moons of Jupiter is seen to pass in front of the disc it's known as a transit. The shadow of the moon can sometimes be seen to cross the planet's disc, this is known as a shadow transit. If the moon passes behind the disc of Jupiter it is called an occultation.

### Cloud belts

When we look at Jupiter, we are not seeing its surface as such, as the planet is made from very dense gas, but the cloud tops of its atmosphere. Due to the fast rotation of the planet, these clouds form into belts of differing colours which are relatively easy to see with a small telescope.

### Galilean moons

These are the largest moons of Jupiter's many satellites and are the only ones visible in amateur telescopes. They were discovered by the famous astronomer Galileo Galilei in 1610 and collectively named after him. Their individual names are Io, Callisto, Europa and Ganymede.

### Great Red Spot

The Great Red Spot on Jupiter is a huge storm which has been raging in the planet's atmosphere for several centuries. The wind speeds in the storm can be up to 640 kilometres (400 miles) per hour, many times stronger than the largest hurricanes here on Earth.

# Jupiter and its key features

Viewing the largest planet in the Solar System and its moons is simple, even with modest optical equipment. Here's how...

**1. Galilean moons**
The moons of Jupiter can be seen with 7x50 or 10x50 binoculars as small points of light either side of the disc of the planet. A small telescope will reveal them as tiny discs in their own right.

**2. Jupiter's belts**
The belts of Jupiter are clouds racing around the planet. A small telescope will show these as three or four bands of differing colours. A larger telescope with a magnification over 100x will reveal detail and structure to them.

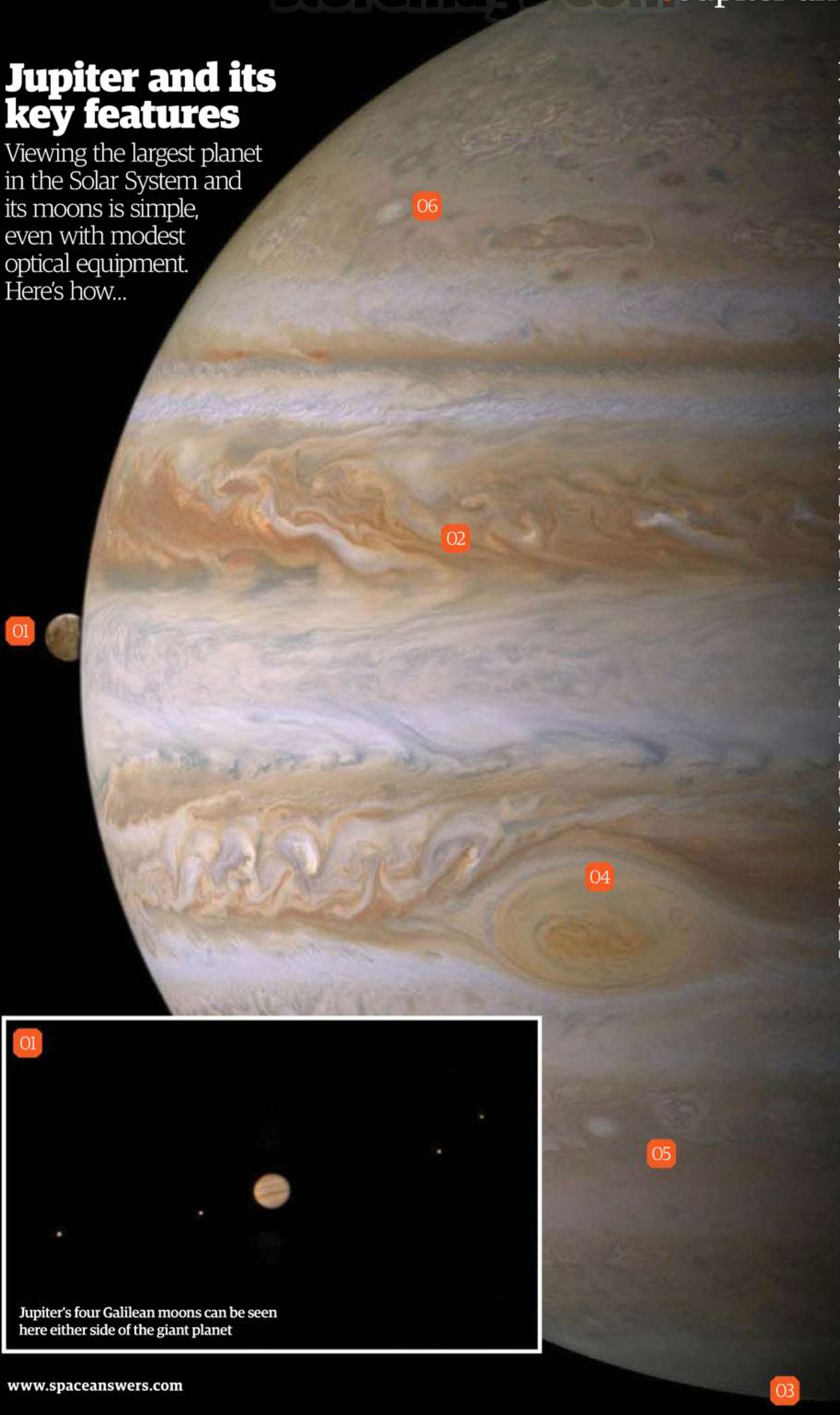
**3. Flattened polar regions**
Because Jupiter rotates at such a speed (its day is only around ten hours), the poles have become slightly squashed making the disc look 'oblate' or not quite perfectly round. You can spot this with binoculars or using a small telescope.

**4. Great Red Spot**
Through a telescope this huge storm looks like a round blob in the South Equatorial Belt. It has a red-brownish colour when viewed through larger telescopes at around 150x.

**5. Oval BA**
This is much harder to spot with a small telescope but larger apertures will show it up with moderate magnifications. It's sometimes referred to as 'Red Spot Junior'. It sits in the South Temperate Belt.

**6. White ovals**
These are more transient features in Jupiter's atmosphere and you'll need a larger telescope and high magnification (over 200x) to see them well. They are usually seen most often in the South Temperate Belt and South Temperate Zone.

**7. Shadow transits**
Even a small telescope will show the small dark spots of the shadows of the moons as they pass over the disc of the planet. They can often be seen to be leading or trailing the transit of the moon itself.



Jupiter's four Galilean moons can be seen here either side of the giant planet

© NASA, Jan Sandberg

# What's in the sky?

Late winter skies reveal a wealth of wonderful constellations and celestial objects

## Open Star Cluster NGC 2281

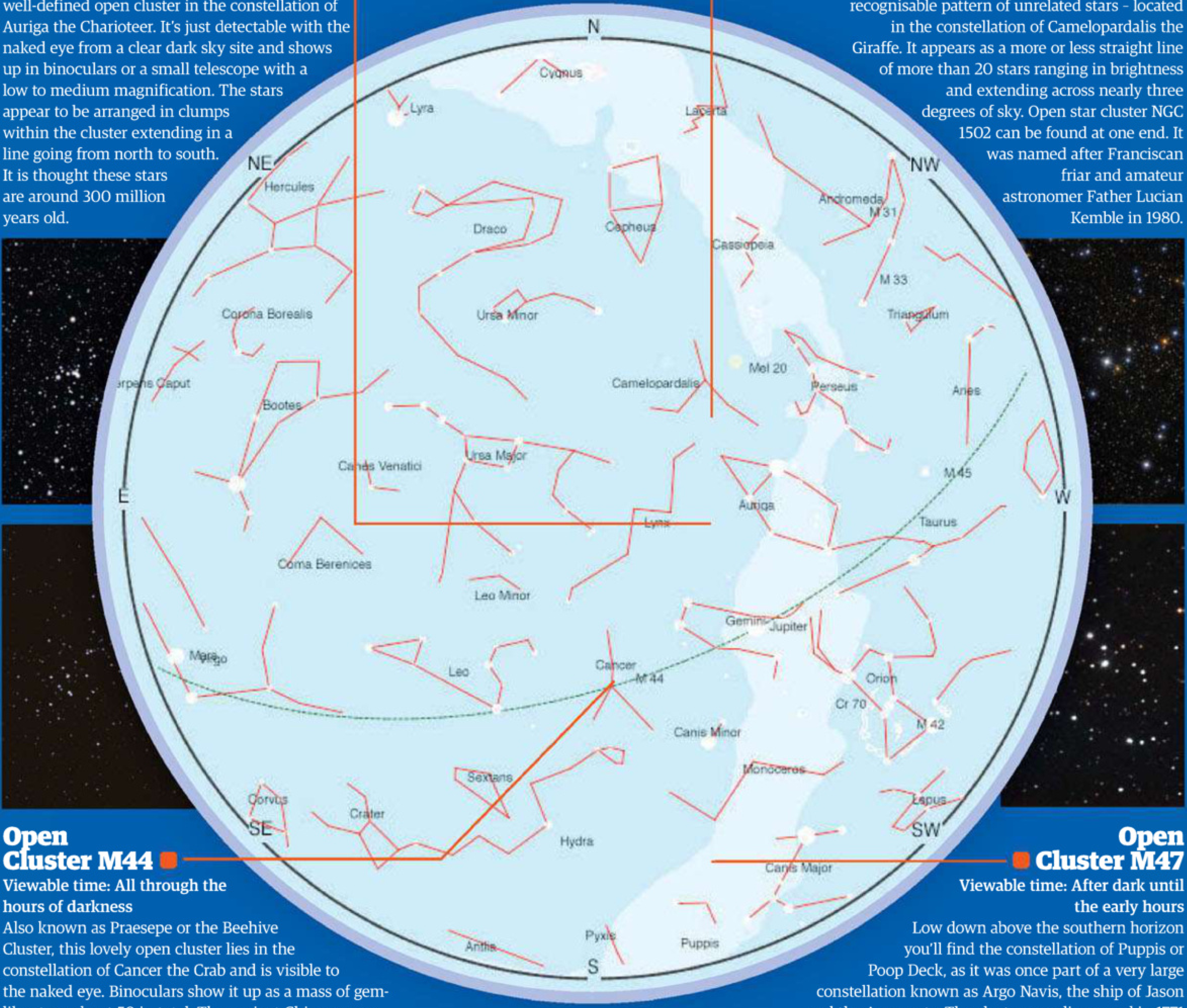
**Viewable time: After dark until a couple of hours before dawn**

NGC 2281 is a medium-sized but not particularly well-defined open cluster in the constellation of Auriga the Charioteer. It's just detectable with the naked eye from a clear dark sky site and shows up in binoculars or a small telescope with a low to medium magnification. The stars appear to be arranged in clumps within the cluster extending in a line going from north to south. It is thought these stars are around 300 million years old.

## Kemble's Cascade

**Viewable time: All through the hours of darkness**

Kemble's Cascade is an asterism - that is a recognisable pattern of unrelated stars - located in the constellation of Camelopardalis the Giraffe. It appears as a more or less straight line of more than 20 stars ranging in brightness and extending across nearly three degrees of sky. Open star cluster NGC 1502 can be found at one end. It was named after Franciscan friar and amateur astronomer Father Lucian Kemble in 1980.



**Northern hemisphere**

## Open Cluster M44

**Viewable time: All through the hours of darkness**

Also known as Praesepe or the Beehive Cluster, this lovely open cluster lies in the constellation of Cancer the Crab and is visible to the naked eye. Binoculars show it up as a mass of gem-like stars, about 50 in total. The ancient Chinese gave this cluster the rather strange name of 'The Exhalation of Piled-up Corpses'! The Beehive describes it rather better, as it does resemble a swarm of bees buzzing around a hive. It is approximately 577 light years away.

## Open Cluster M47

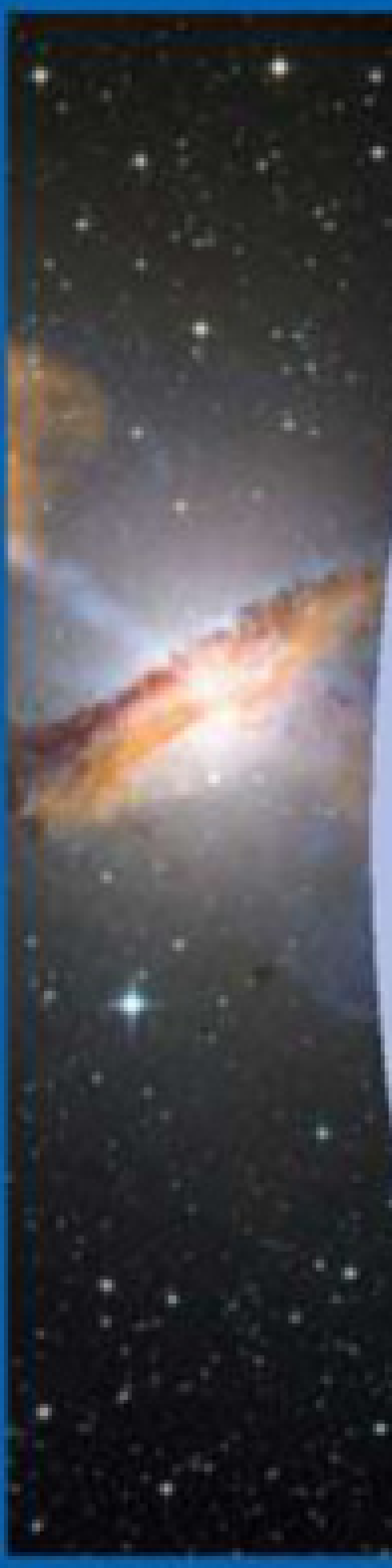
**Viewable time: After dark until the early hours**

Low down above the southern horizon you'll find the constellation of Puppis or Poop Deck, as it was once part of a very large constellation known as Argo Navis, the ship of Jason and the Argonauts. The cluster was discovered in 1771 by Charles Messier, whose catalogue number it now bears. It can be seen as a faint misty patch with the naked eye and shows up well in binoculars and small telescopes. It lays about 1,600 light years from us.

## Galaxy NGC 5128

**Viewable time: All through the hours of darkness**

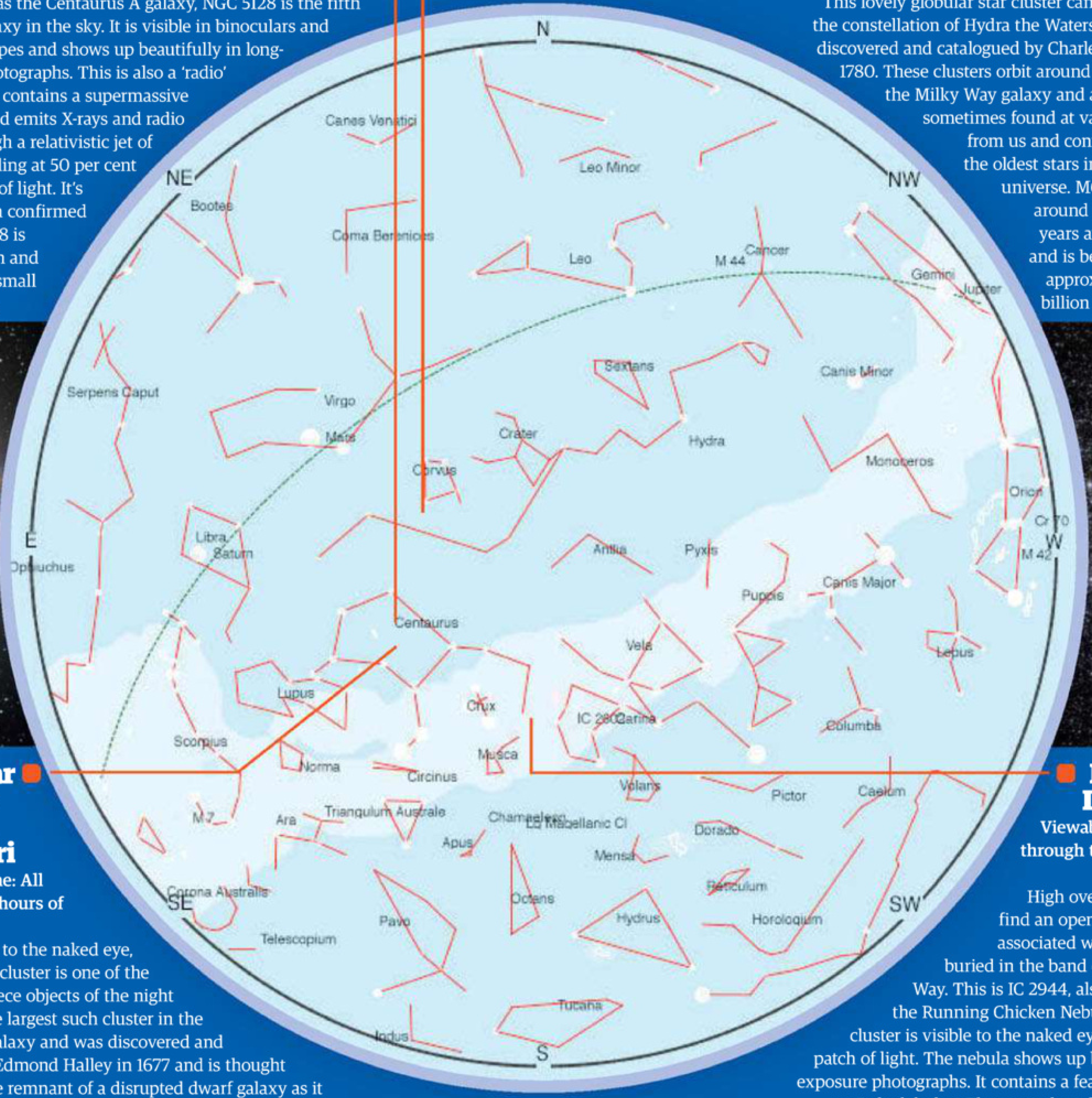
Also known as the Centaurus A galaxy, NGC 5128 is the fifth brightest galaxy in the sky. It is visible in binoculars and small telescopes and shows up beautifully in long-exposure photographs. This is also a 'radio' galaxy and it contains a supermassive black hole and emits X-rays and radio waves through a relativistic jet of matter travelling at 50 per cent of the speed of light. It's recently been confirmed that NGC 5128 is colliding with and devouring a small spiral galaxy.



## Globular Cluster M68

**Viewable time: All through the hours of darkness**

This lovely globular star cluster can be found in the constellation of Hydra the Watersnake. It was discovered and catalogued by Charles Messier in 1780. These clusters orbit around the plane of the Milky Way galaxy and are therefore sometimes found at vast distances from us and contain some of the oldest stars in the known universe. M68 is located around 33,000 light years away from us and is believed to be approximately 11.2 billion years of age.



**Southern hemisphere**

## Globular Cluster Omega Centauri

**Viewable time: All through the hours of darkness**

Easily visible to the naked eye, this globular cluster is one of the great showpiece objects of the night skies. It is the largest such cluster in the Milky Way galaxy and was discovered and recorded by Edmond Halley in 1677 and is thought to be the core remnant of a disrupted dwarf galaxy as it seems quite different from other globulars. It is located at a distance of around 16,000 light years from us and is probably around 12 billion years old.

## Nebula IC 2944

**Viewable time: All through the hours of darkness**

High overhead you'll find an open star cluster associated with a nebula buried in the band of the Milky Way. This is IC 2944, also known as the Running Chicken Nebula. The star cluster is visible to the naked eye as a misty patch of light. The nebula shows up best in long-exposure photographs. It contains a feature known as 'Bok globules'. These are thought to be star-forming regions, although no evidence of this has been found here.

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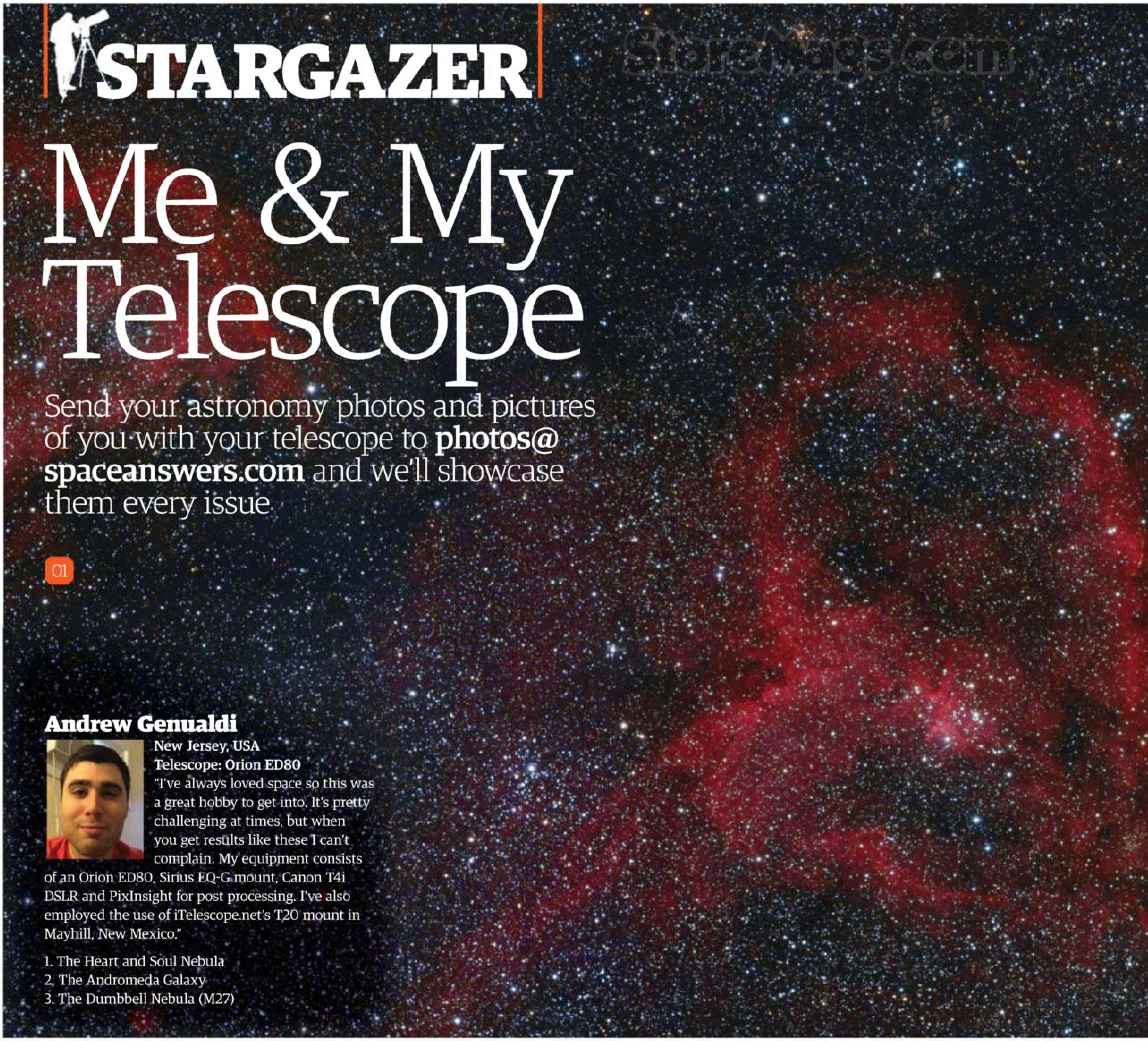
# Me & My Telescope

Send your astronomy photos and pictures of you with your telescope to **photos@spaceanswers.com** and we'll showcase them every issue

01



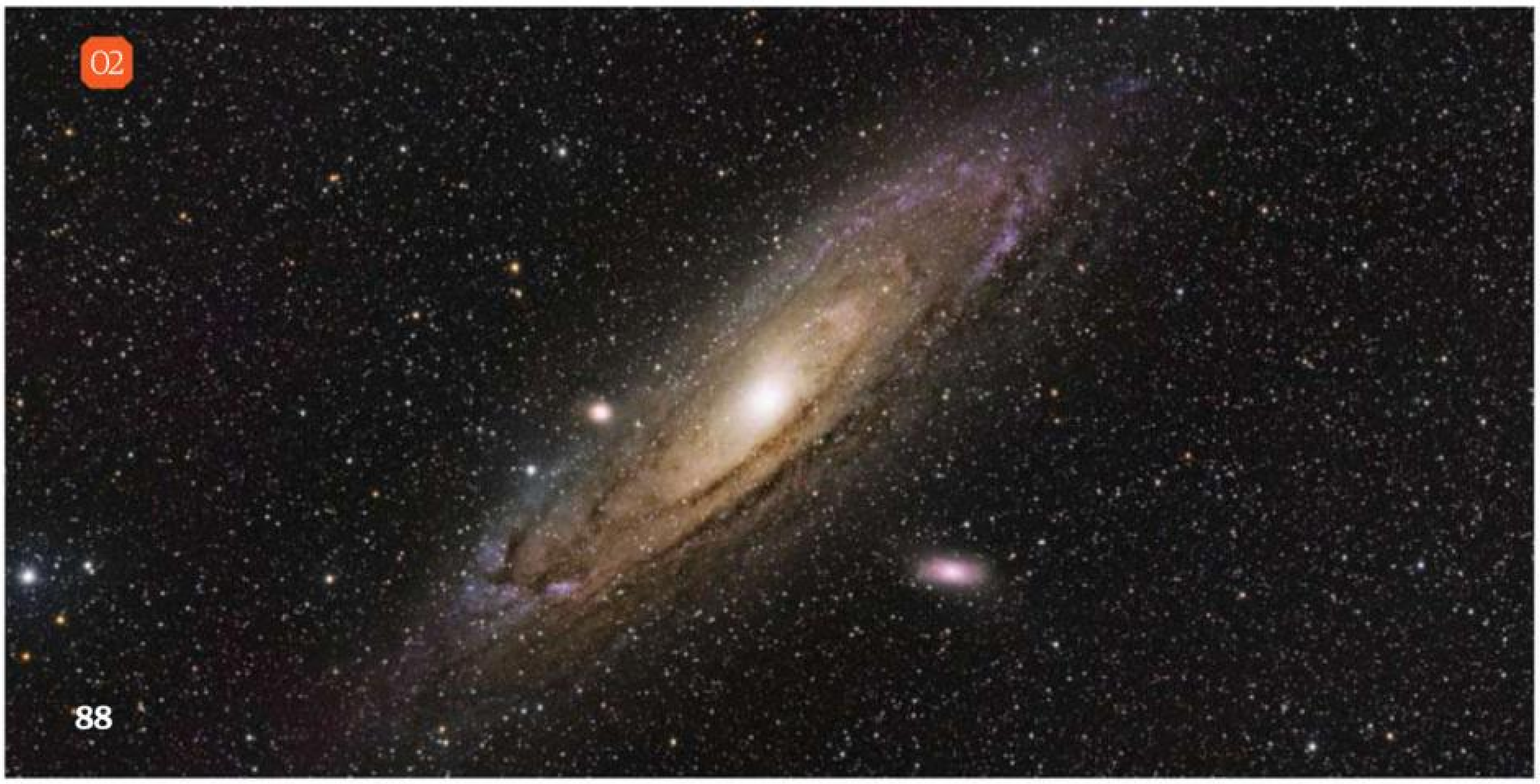
**Andrew Genualdi**

**New Jersey, USA**
**Telescope: Orion ED80**

"I've always loved space so this was a great hobby to get into. It's pretty challenging at times, but when you get results like these I can't complain. My equipment consists of an Orion ED80, Sirius EQ-G mount, Canon T4i DSLR and PixInsight for post processing. I've also employed the use of iTelescope.net's T20 mount in Mayhill, New Mexico."

1. The Heart and Soul Nebula
2. The Andromeda Galaxy
3. The Dumbbell Nebula (M27)

02



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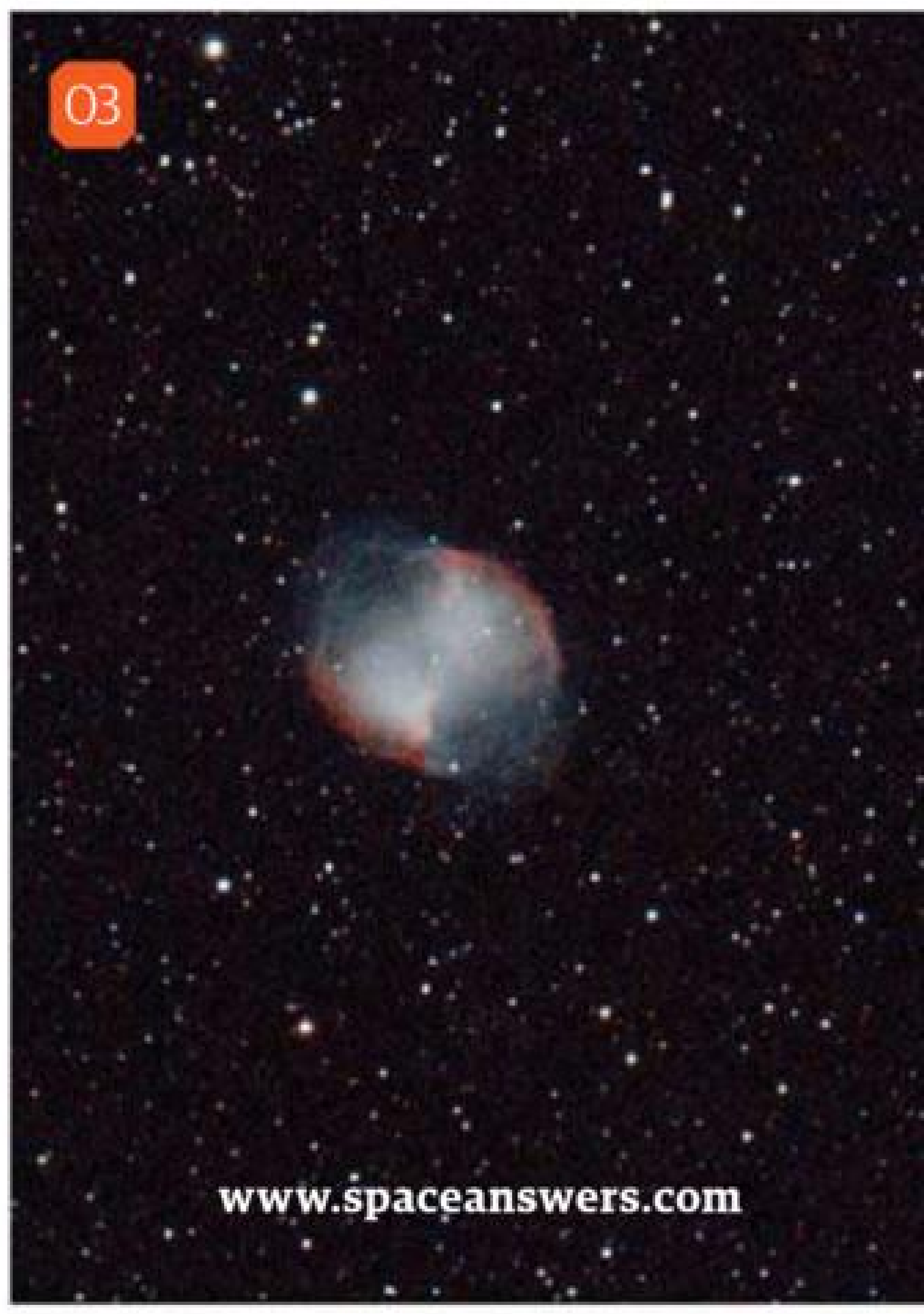


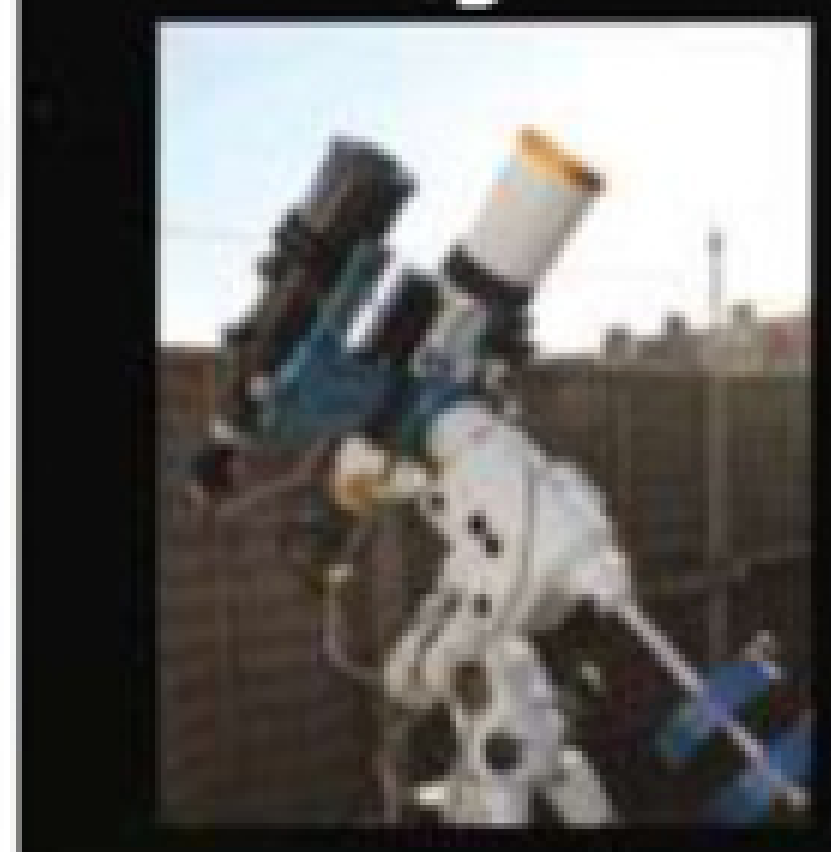
## Henry Dueck

**North Rhine-Westphalia, Germany**

**Telescope: 150/750 Meade Newtonian**

"I am 28 years old and live in northern Germany. I live in a rural part of North Rhine-Westphalia and shoot my pictures from my front yard. I started with visual astronomy and kind of stumbled into astrophotography when I tried to take a picture of the Moon via a phone. From then on, things got out of hand and I am now several hundred euros poorer! I capture images with a 150/750 Meade Newtonian telescope on a Bresser MON-2 mount using a Canon 1100D."

## Andy Lee



**West Sussex, UK**

**Telescope: William Optics 98mm FLT**

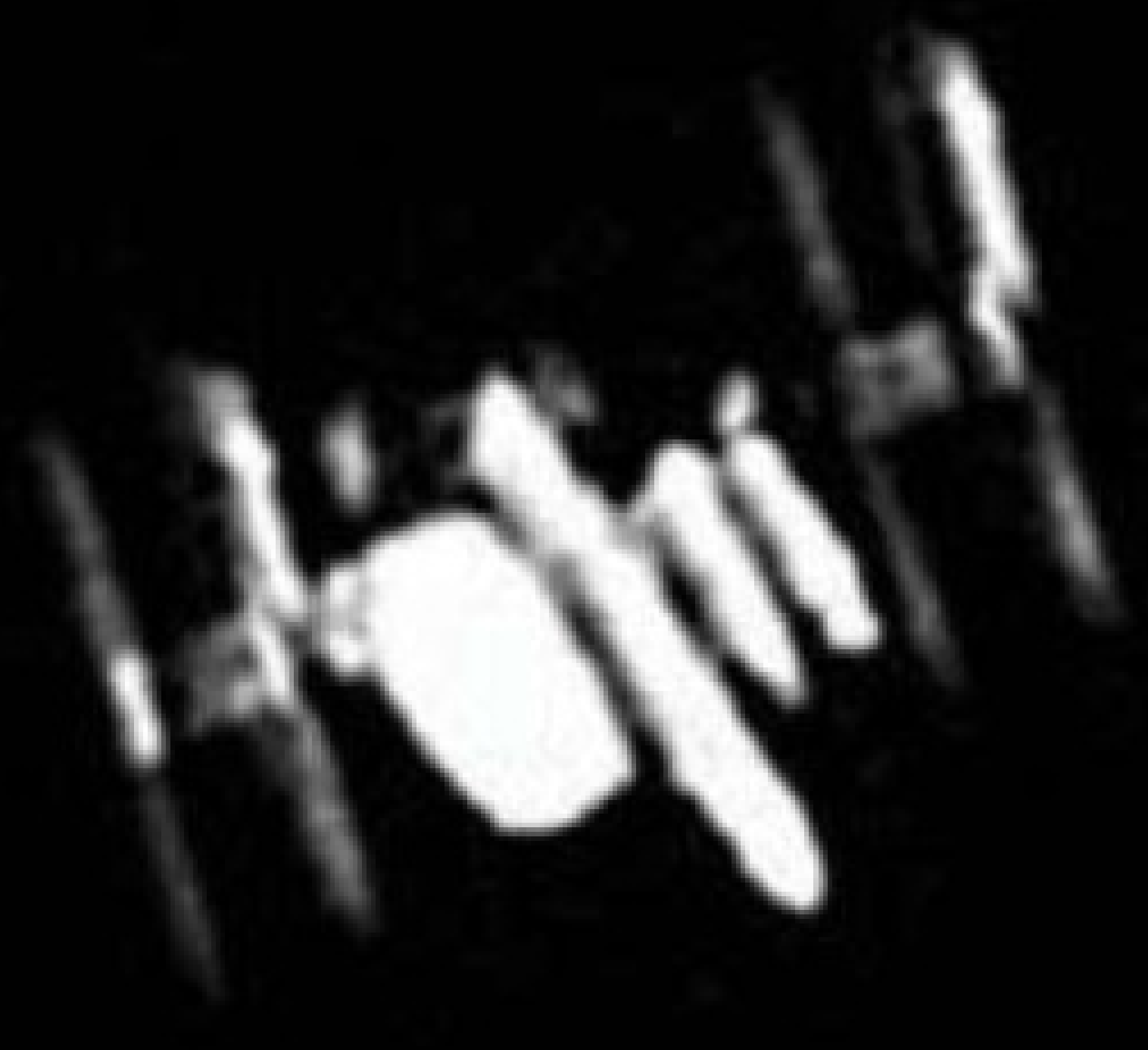
"I thought you might like to see a couple of images I took recently of Comet C/2013 R1 Lovejoy and also of M31 with a meteor whizzing past. Both images were taken with my William Optics 98mm FLT with a MkIV reducer/flattener, Canon 50D. They were guided using a SkyWatcher ST80 and a QHY5 guide camera with a 0.5x reducer, all mounted on a SkyWatcher Pro 6 mount."

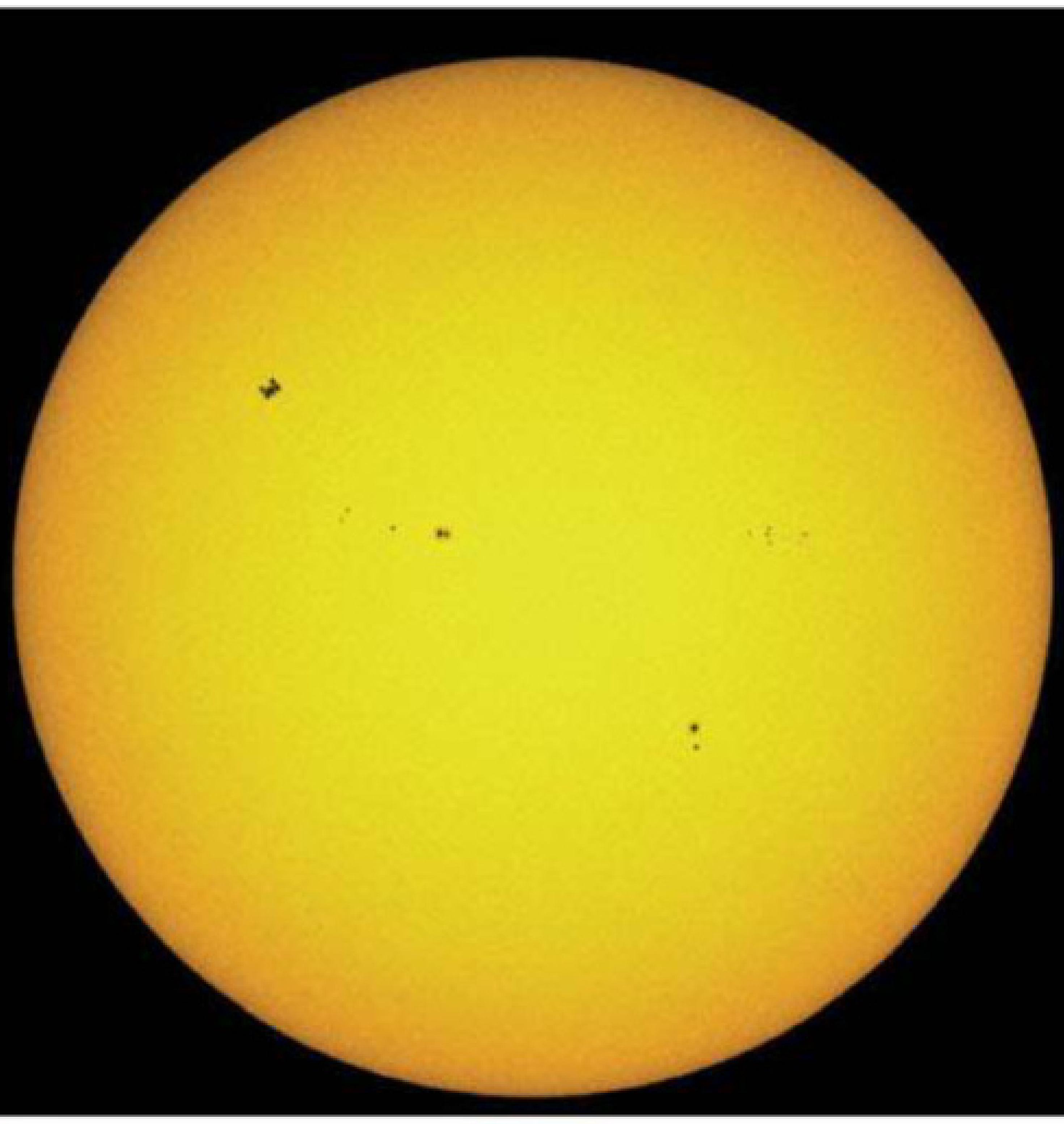
## Nicolas Kizilian

**Auffargis, France**

**Telescope: Meade 2080B OTA**

"I'm a French amateur astronomer living 30 kilometres [19 miles] from Paris. I'm 35 years old and have been practising since 1994. I haven't changed my telescope since then, and still have my good old Meade 2080B OTA. Inspired by the work of the French astrophotographer Thierry Legault, I started shooting the ISS alone or during Moon and Sun transits. My next step will be to start imaging deep sky objects with a DSLR."





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# Stargazing stories

Email your story of how you got into astronomy to **photos@spaceanswers.com** for a chance to feature in **All About Space**

## Mark Woodland

**Location:** Bath, UK
**Info:** Astronomer for 12 years
**Twitter:** @mw5868
**Current Rig**
**Telescope:** SkyWatcher 200, SkyWatcher 102
**Mount:** EQ5, SynScan GOTO
**Other:** Pentax *ist DS DSLR

"Ever since I was little, I had been taught about the night sky, being able to locate Polaris, and the most recognisable constellations, Orion and Ursa Major. It wasn't until I was in my second year of A levels that my physics teacher at the time started running the GCSE astronomy course. I already had an interest, so why not get a qualification from it, too? As the course progressed I was able to borrow a small four-inch Newtonian telescope from him. This opened up a whole new world to me. I decided I wanted a scope of my own, so my parents bought me my eight-inch for Christmas and it went on from there. The first planet I ever saw through it was Saturn, from which point I was hooked. I subsequently went on to start an astrophysics degree, which I am still studying.

"I always did my observations from my garden, due to the size of my scope, which persuaded me to buy the more portable SkyWatcher 102. I often head up to the top of the Mendip Hills, where the skies are amazingly clear, either with the astronomy group Wells & Mendip Astronomers or to help at the observatory housing an 18-inch telescope. My hobby has taken me to observatories all around, including Cornwall and the island of Mallorca, where I will be spending a week in April on a research project. I have also been very lucky to be elected a Fellow of the Royal Astronomical Society." ●

> "I often head up to the top of the Mendip Hills, where the skies are amazingly clear"

## Mark's top 3 tips

### 1. Use social media

There are many astronomers on Twitter and Facebook who are always willing to chat, and give advice.

### 2. Volunteer work

Volunteer at a local observatory. This is a great experience working with (mostly) much larger telescopes.

### 3. Join a club

Astronomy clubs are a great way to network with fellow stargazers, and to share experiences and knowledge.

"Both telescopes set up for solar observations in my garden"

"The 2007 lunar eclipse. Image taken using eight-inch Newtonian and Pentax DSLR"

"My first-ever astrophotography image (2006). Taken with a Pentax compact, presented to the eyepiece of my eight-inch Newtonian"

"Me setting up my scope for the Wave at Saturn event on the Mendips"

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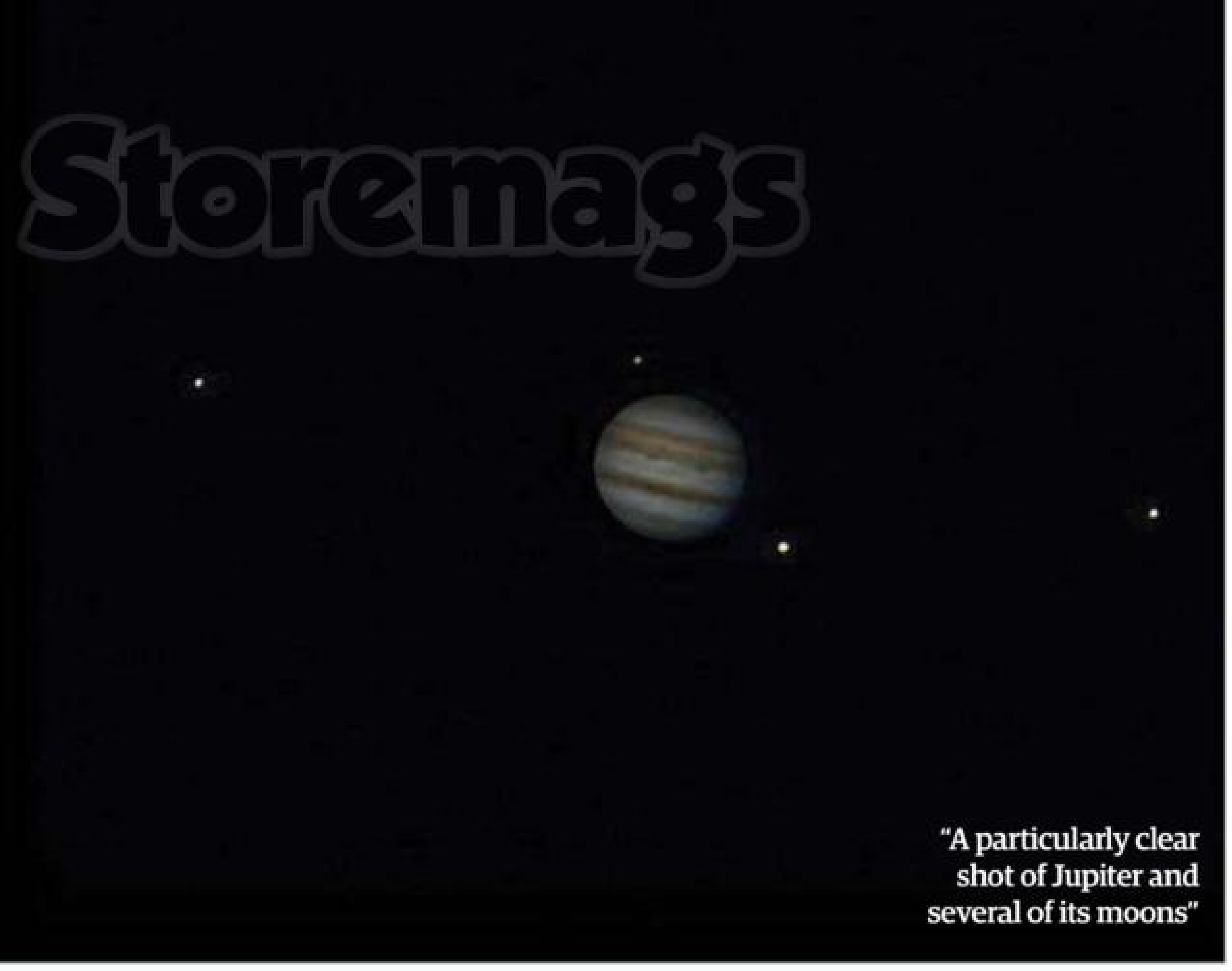
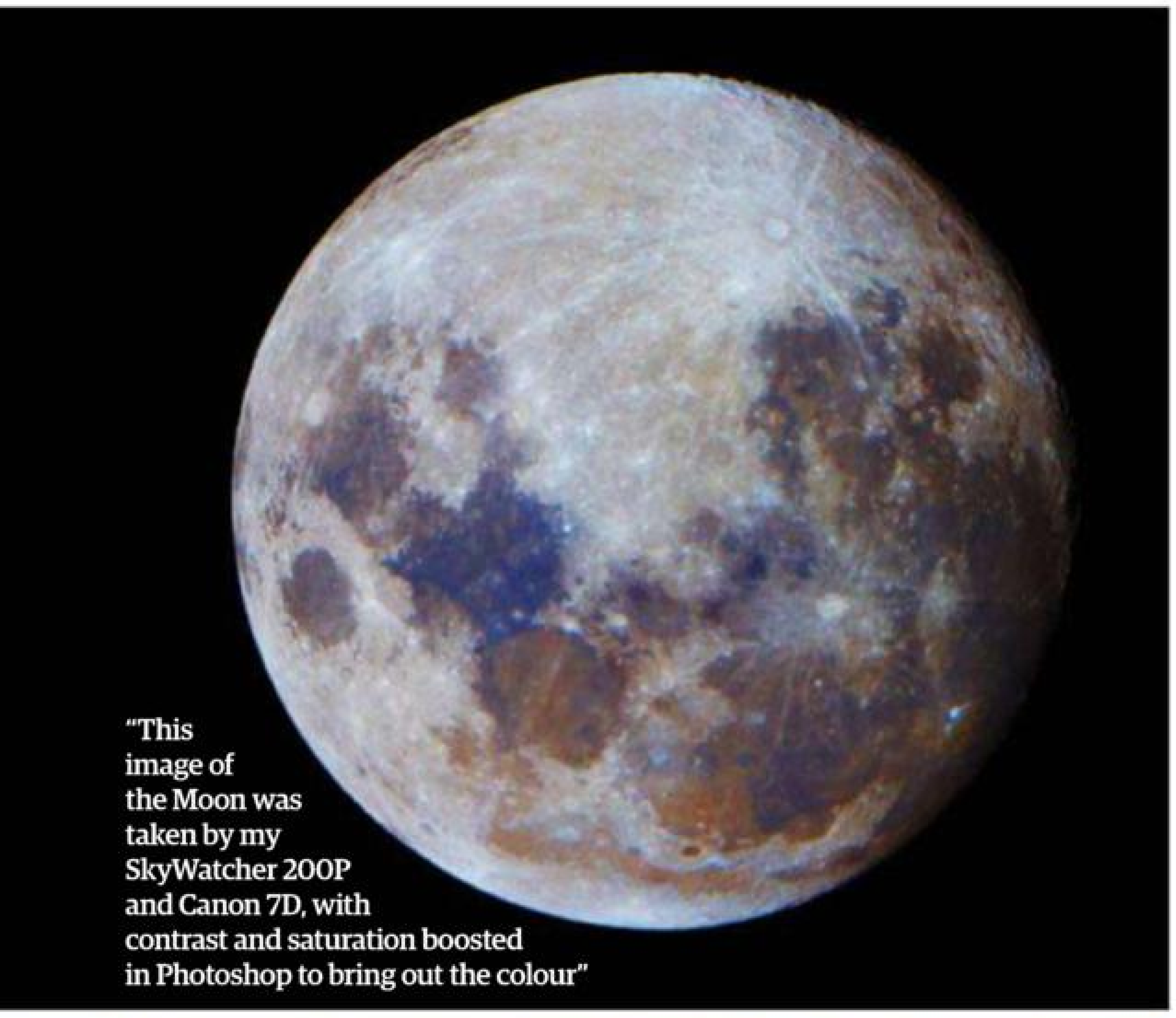
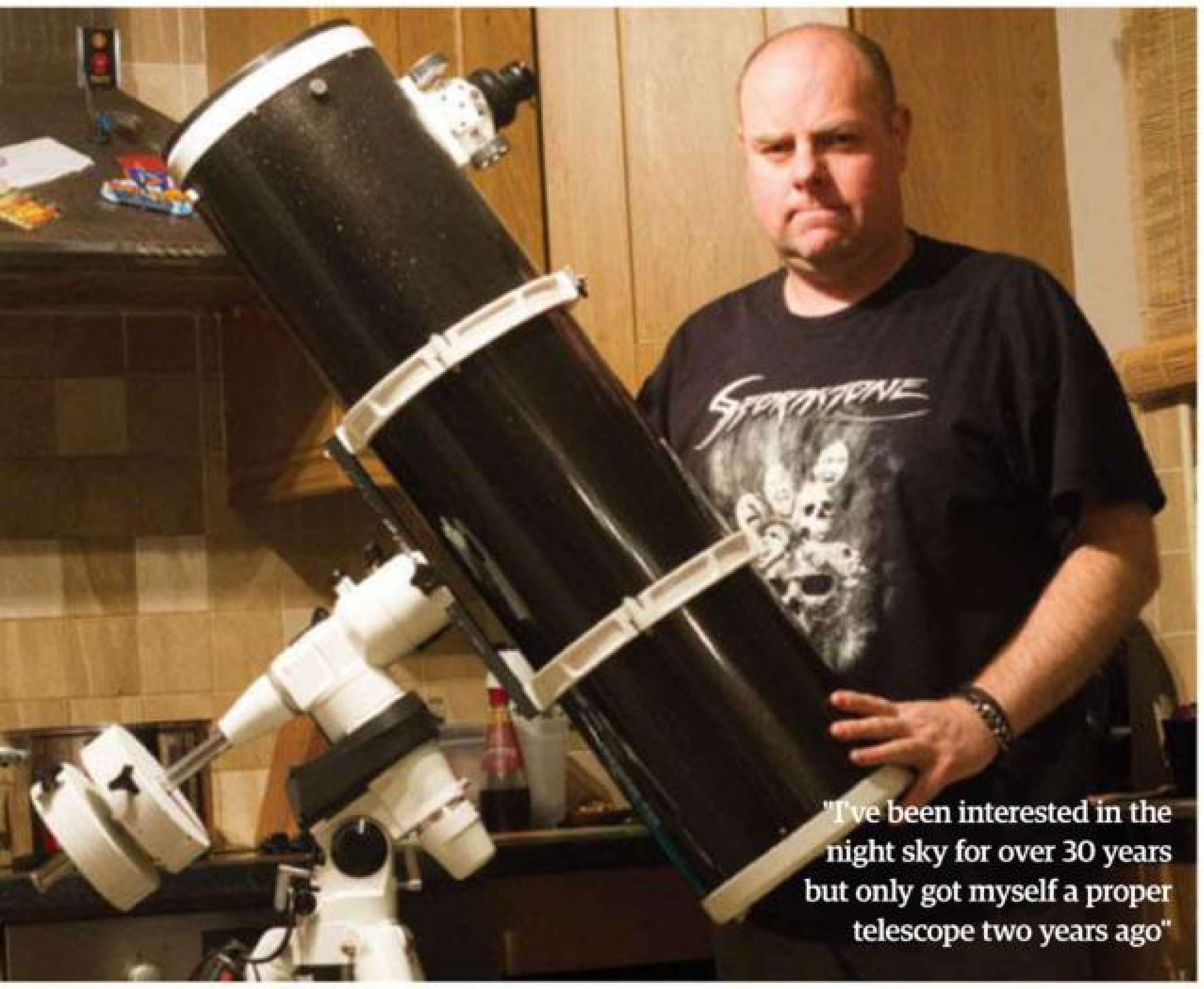


"A particularly clear shot of Jupiter and several of its moons"



"This image of the Moon was taken by my SkyWatcher 200P and Canon 7D, with contrast and saturation boosted in Photoshop to bring out the colour"



"I've been interested in the night sky for over 30 years but only got myself a proper telescope two years ago"

# Paul Wharton

**Location:** County Armagh, Northern Ireland
**Info:** Astronomer for two years
**Twitter:** @paulwharton1970
**Current Rig**
**Telescope:** SkyWatcher 200P
**Mount:** EQ5 Pro
**Other:** Philips SPC900 webcam, Canon 7D

"I have been interested in the night sky for over 30 years but only got myself a proper telescope two years ago. I had been a photographer for five years and decided to merge my hobby with astronomy.

"As I don't drive I do the majority of my viewing and imaging in my back garden. It backs on to my neighbour's back garden so there are no streetlights about. I haven't really been anywhere yet astronomy-wise but I do hope to travel to Iceland someday to view the northern lights.

"In January 2013, a friend and myself went to Northern Ireland's main Stargazing Live event at Lough Neagh Discovery Centre. We decided to bring our telescopes as the Irish Astronomical Association would be there and we planned on setting up beside them. To our surprise they were set up indoors and had no plans on moving outside as they said it would be cloudy!

"The two of us set up anyway in the car park as we were expecting it to clear up. I had my telescope set up for the adults to view through and my friend Duane set his tripod up lower down so the kids could have a look. Within an hour it did clear up and the queues to view Jupiter through our telescopes were over 200 long! Many of them told us that this was the highlight of their night and thanked us for giving them the chance to view the gas giant and its Galilean moons. That was my most rewarding night as an amateur astronomer." ■

## Paul's top 3 tips

### 1. Binoculars

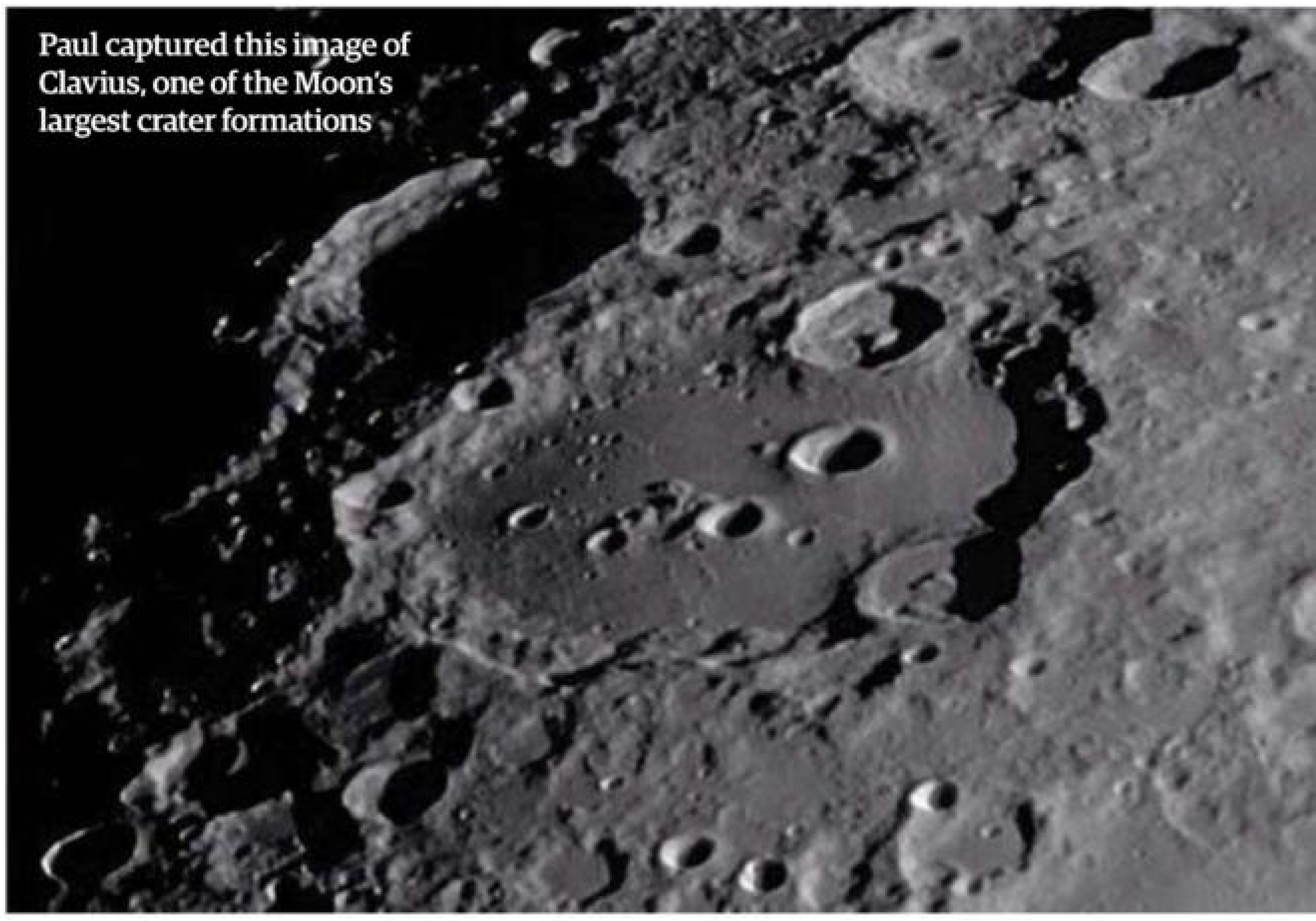
Start off with binoculars and learn the sky. A decent pair will allow you to see Jupiter and its moons. M45 (the Pleiades) looks amazing through binoculars.

### 2. Get some pictures

Try some basic astrophotography by simply holding your camera phone up to your telescope's eyepiece and shooting.

### 3. Fine-tuning your scope

Clip a clothes peg on to your telescope focusing wheel. This makes it far easier to fine-tune the focus by simply nudging the peg.



Paul captured this image of Clavius, one of the Moon's largest crater formations

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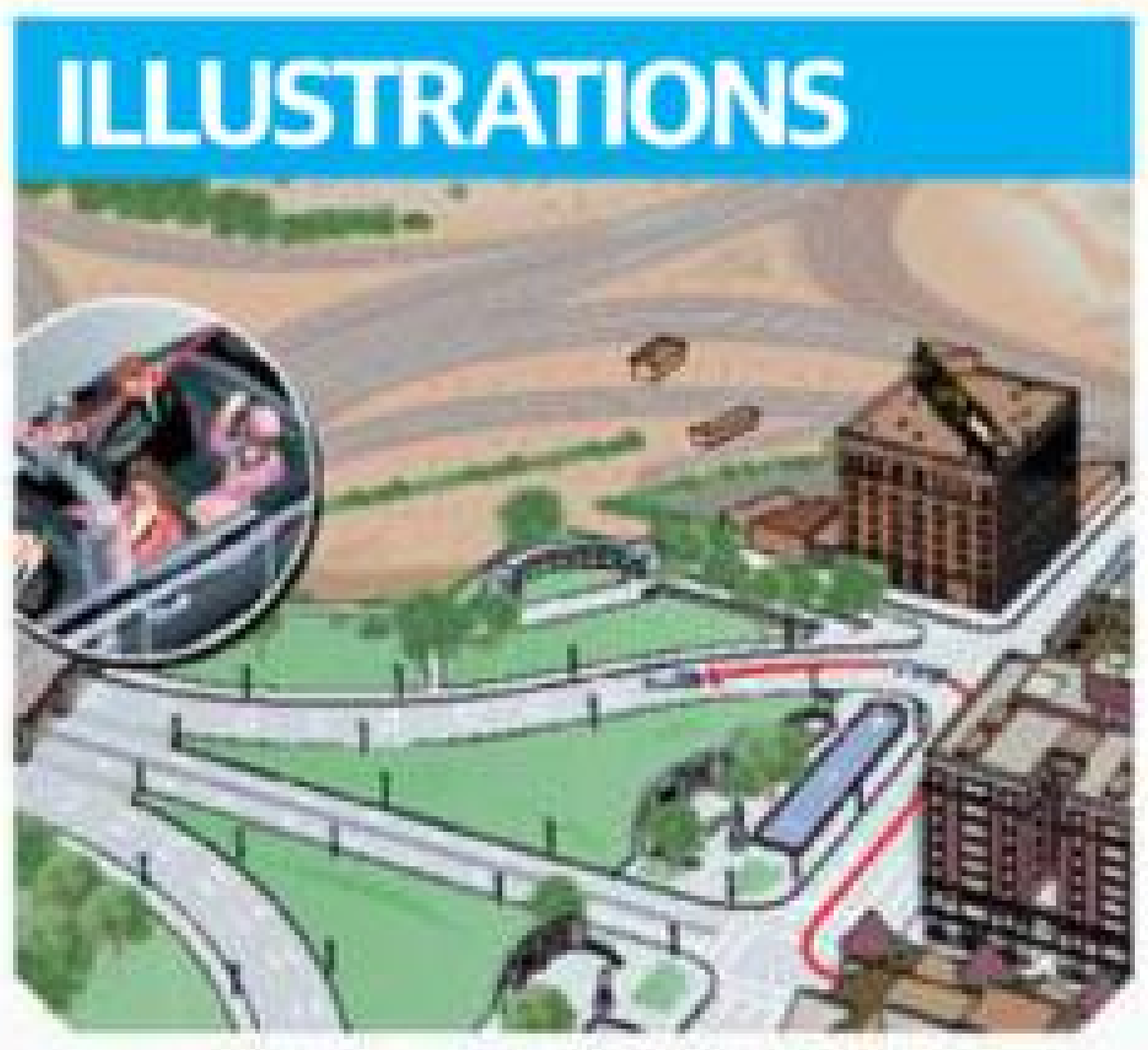

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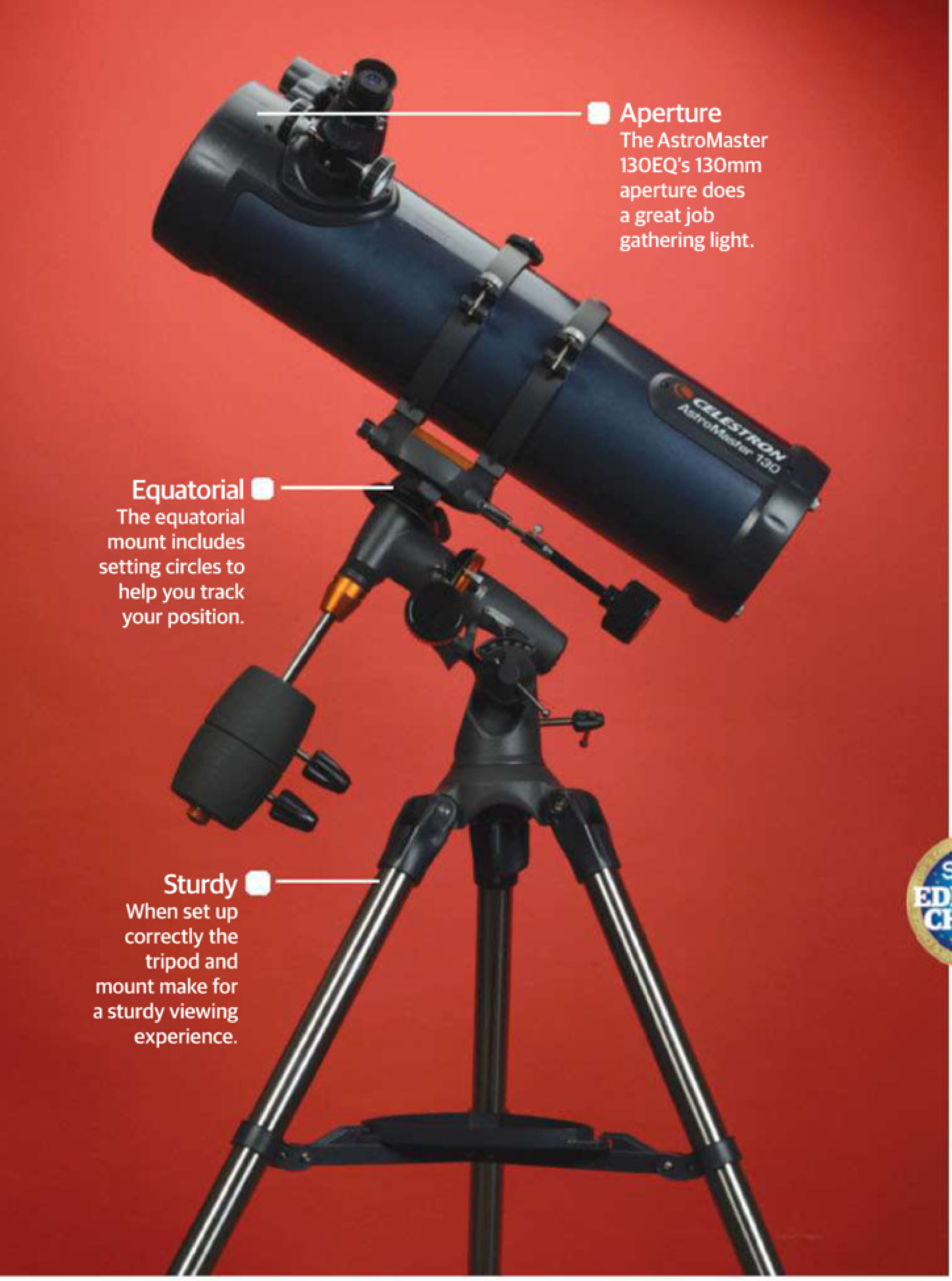
# Celestron Astromaster 130EQ

## A fantastic telescope that's great for both novice and experienced astronomers

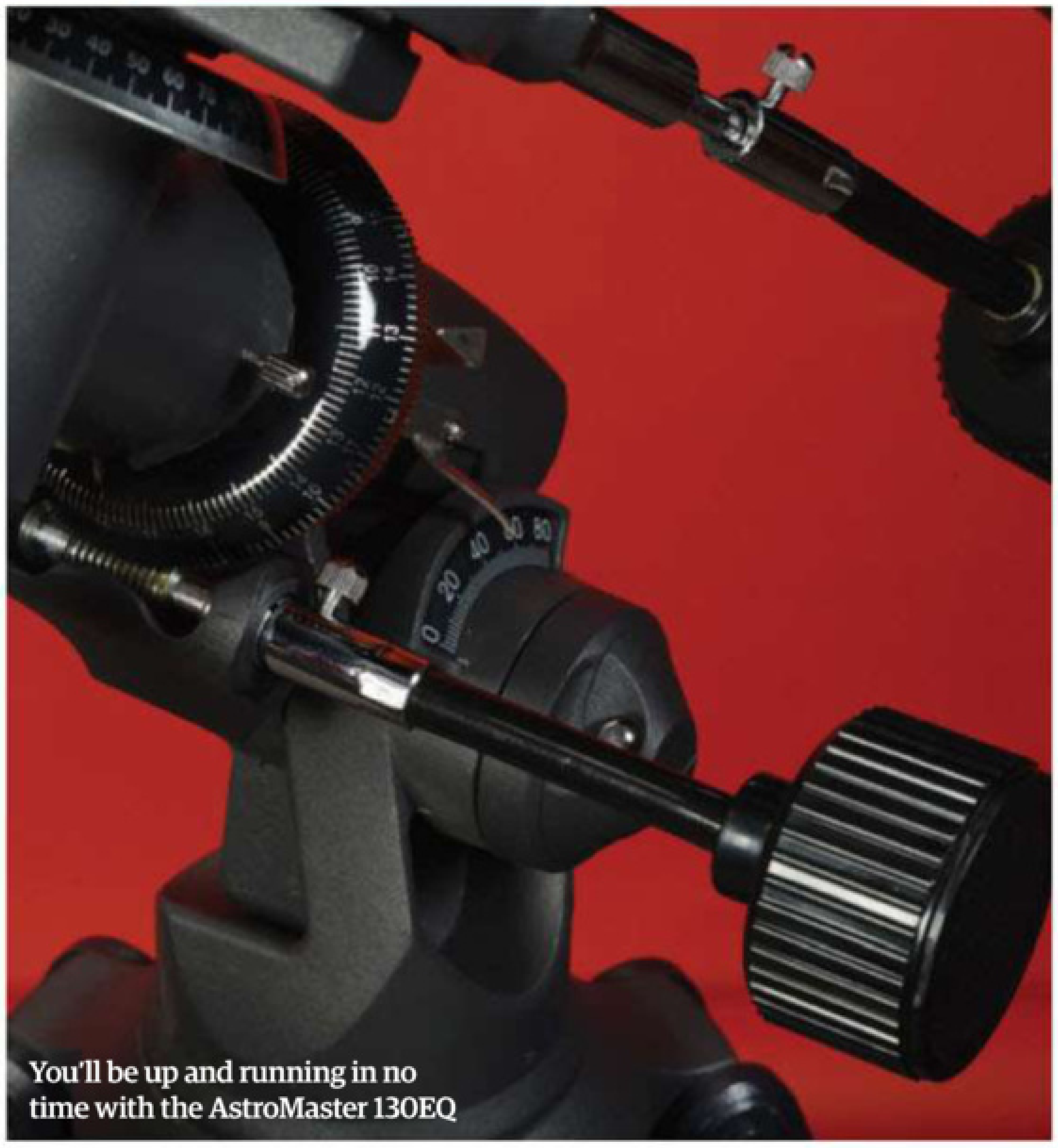


**Aperture**
The AstroMaster 130EQ's 130mm aperture does a great job gathering light.

**Equatorial**
The equatorial mount includes setting circles to help you track your position.

**Sturdy**
When set up correctly the tripod and mount make for a sturdy viewing experience.

The AstroMaster 130EQ offers excellent visuals at an affordable price



You'll be up and running in no time with the AstroMaster 130EQ

## Telescope advice

**Cost:** £160/$396
**From:** www.picstop.co.uk
**Type:** Reflector
**Aperture:** 130mm
**Focal length**: 650mm
**Magnification:** 65x

If you're looking for an affordable and portable telescope that still boasts the power of some of its larger siblings, then look no further than the excellent AstroMaster 130EQ from Celestron. It's a top reflector telescope with an effective equatorial mount that will give you an impressive astronomy experience.

The AstroMaster 130EQ is a reasonably sizeable telescope, especially considering the price, with an excellent light-gathering capability. It'll rival other similar telescopes in the clarity of its visuals. The entire assembly, meanwhile, is very simple to get up and running. Everything snaps together with ease, and aside from some minor adjustments to the equatorial mount you shouldn't have any problems setting up.

The mount itself is superb, with setting circles enabling you to find and track objects in the night sky. There's also a motor drive available (sold separately) if you don't want to use the focusing knobs that are supplied with the telescope. The mount has a sturdy feel to it once set up correctly, so you shouldn't have too many problems with wobble.

Moving the telescope on the mount is a breeze, and the whole assembly is very smooth. The views you'll get through the telescope are also excellent. As mentioned earlier the sizeable aperture makes for an enjoyable experience while the high-quality lenses inside the scope give you exceptional clarity when viewing a variety of objects.

Overall we greatly enjoyed our experience with the AstroMaster 130EQ and, given the price and quality on offer, we'd highly recommend it to someone either looking to start a hobby in astronomy or to upgrade from an existing telescope. ■

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MARC READ
Acidalia Planitia
Mamers Valles
Arabia Terra
Cassini
Meridiani Planum
All About Space
EDITOR'S CHOICE

## 1 Book
### Philip's Stargazing With A Telescope

**Cost:** £8.99/$11.89

**From:** www.octopusbooks.co.uk

If you've ever considered taking up astronomy but have been daunted by everything there is to know, this book by Robin Scagell is an essential buy. Inside you'll find extensive chapters on all areas of astronomy that will help newcomers pick up the hobby. Scagell runs through the kit you'll need and what it all means, discusses how to get your telescope up and running and also outlines what to observe in the night sky. Within each chapter are helpful and illustrative images as well, showing you different types of kit and what you can expect to see. Written in an accessible style, Scagell's comprehensive guide to stargazing with a telescope is a great choice for novice astronomers. ■

## 2 Binoculars
### Celestron TrailSeeker 8x32s

**Cost:** £235/$219.95

**From:** uk.hama.com

If you're after a pair of binoculars this winter then look no further than Celestron's TrailSeeker 8x32s. They boast crystal-clear viewing and a lightweight design that'll ensure you have a great time checking out the night sky, whether you're in your garden or out and about. The nitrogen-purged fog-proof lenses stop the weather hampering your view and these binoculars also have the added bonus of being waterproof. A wide field of view lets you browse the stars and planets with ease, while the magnesium alloy body is sturdy and not prone to damage through rough and tumble. Together with a reasonable price, the TrailSeeker 8x32s are a worthy purchase. ■

## 3 Book
### New Stars For Old

**Cost:** £18/$9.05 (US kindle edition only)

**From:** www.amazon.co.uk

If you've ever been interested in historical tales of astronomy then we'd suggest picking this book up. Fusing fact with fiction, author Marc Read tells 20 stories from the history of astronomy, focusing on the people behind the stories. From Aristotle to Newton, each chapter focuses on a key moment in a particular astronomer's life that helped define modern astronomy. The writing style is entertaining and engaging, weaving tales of accomplishment with those of personal hardship. The inclusion of notes at the end of each chapter to separate fact from fiction is welcome, and ensures readers will both enjoy the book as well as learning of the history of astronomy in the process. ■

## 4 App
### Mars Globe

**Cost:** Free

**From:** iTunes

This app for iPhone, iPod touch and iPad is unbelievable in its scope and, best of all, it's free! Mars Globe is a 3D rendering of the Red Planet that enables you to explore its surface in exceptional detail. There are over 1,500 surface features to discover, with each including information and links to external websites for further reading. From Curiosity to Olympus Mons there is a stupendous amount of stuff for you to observe and study here, and it's all accessible with a few simple swipes or taps of the screen. And, what's more, you can even change the 'local time' to Mars time so you can see what time it is at different places on Mars, such as where NASA's rovers currently are. For iOS owners this is an essential download. ■

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# CELESTRON TELESCOPE

## We've got an awesome reflector telescope up for grabs this month

Courtesy of PicStop (www.picstop.co.uk) we've got a Celestron AstroMaster 130EQ worth £160 to give away this issue, just in time to make the most of the dark skies in winter. The AstroMaster 130EQ is a reflector telescope that boasts an aperture of 130 millimetres (5.1 inches), perfect for observing a host of objects in the night sky. Its simple no-tool assembly and equatorial mount also make this a great telescope for astronomers of all levels.

To enter, all you have to do is answer this question:

**Q: Which of these does HST stand for?**

**A. Hubble Space Telescope**

**B. Hydrogen Spectrum Tax**

**C. Heavy Science Thing**

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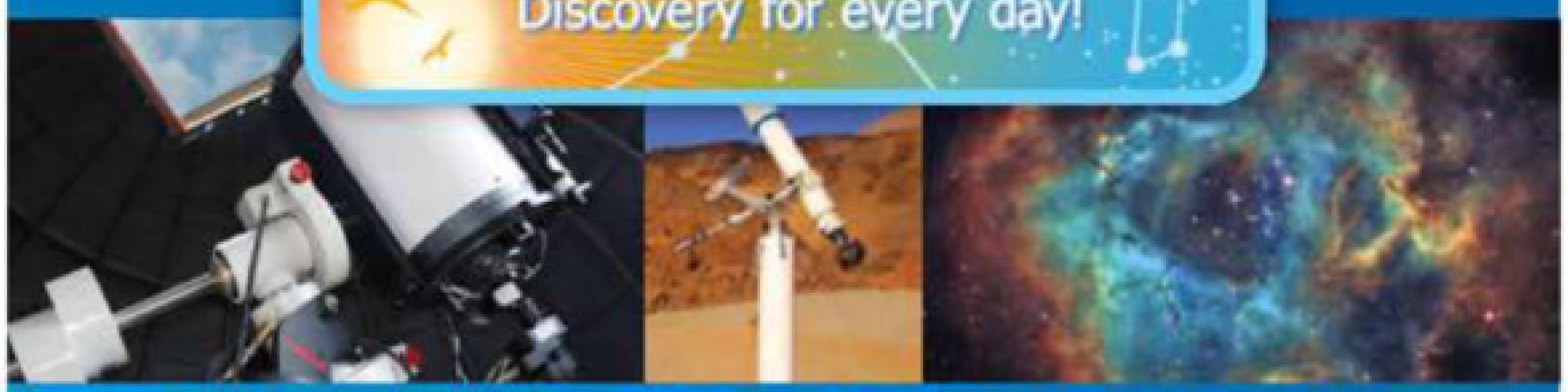

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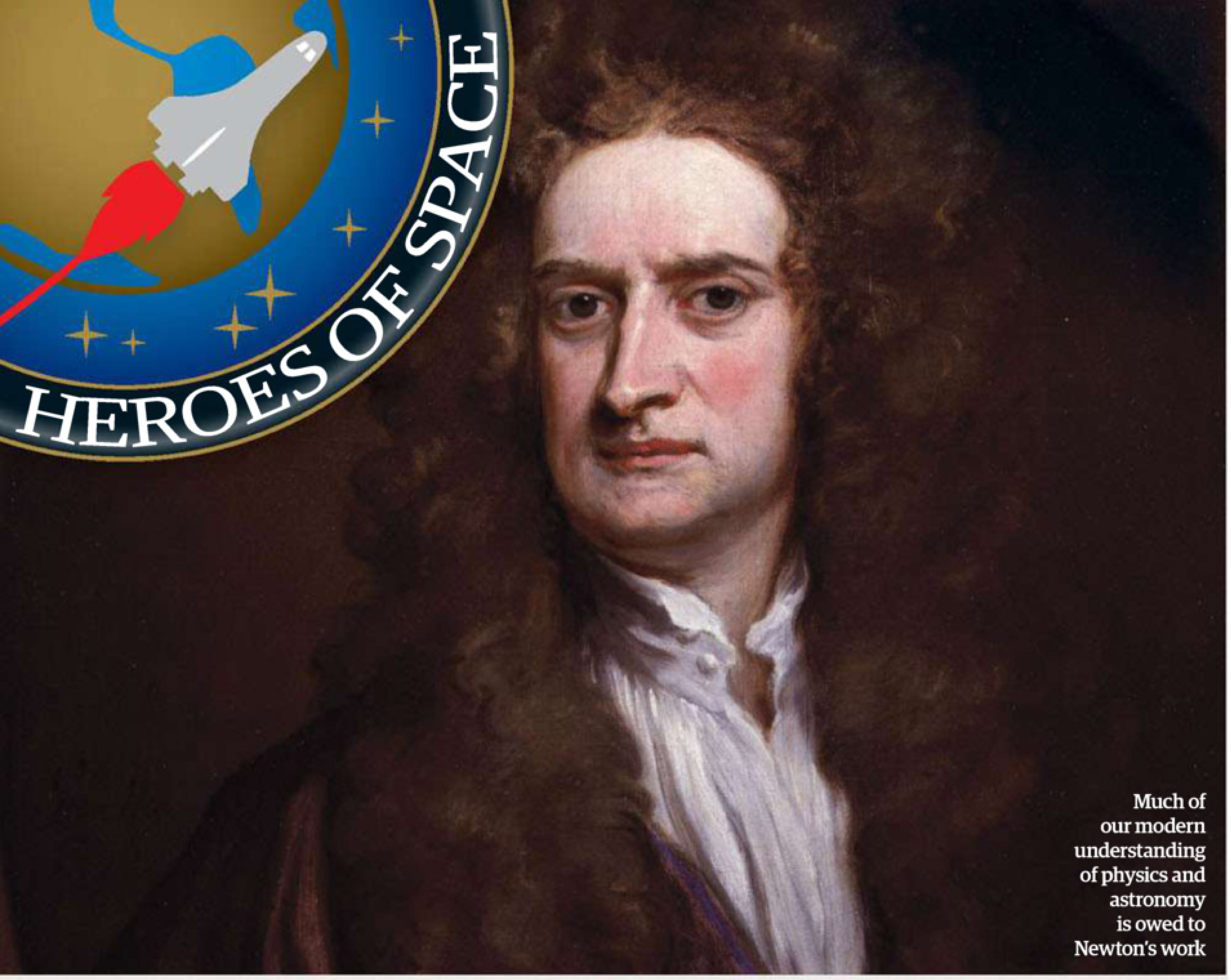

Much of our modern understanding of physics and astronomy is owed to Newton's work

# Isaac Newton

## The life and work of arguably the world's greatest scientific mind

Sir Isaac Newton is considered by many to be one of the most important scientists to have ever lived. Despite a troubled youth and some bitter rivalries in adulthood, his contributions to the world of science are perhaps unprecedented in their scope and application.

Born prematurely on Christmas day 1642, his childhood was thrown into turmoil at the age of three when his single mother left to raise a second family. He was left to the care of his grandmother in Woolsthorpe, Lincolnshire, until his mother's return in 1653, although by then their separation coupled with his hatred for his stepfather would have serious implications on his later life.

After rejecting the chance to follow in his father's footsteps to become a farmer, a profession Newton was not remotely interested in pursuing, he was accepted to Cambridge University in June 1661. Here he came into his element, although largely unbeknown to his professors at the time as he preferred to study privately. In 1665, having earned his bachelor's degree, he was able to continue working alone in unusual circumstances when the university was closed due to the plague. He used this time to formulate many of the theories in mathematics and philosophy that would influence his later work.

Before his 27th birthday in 1669, Newton would come to hold the prestigious position of Lucasian Professor of Mathematics at Cambridge. In 1672 he published his first paper, a controversial study on the nature of colour, which began a bitter rivalry with the scientist Robert Hooke. These tussles left Newton emotionally frail, in 1678 he suffered a breakdown and the following year his mother died. He became isolated and withdrawn, and became devoted to alchemical studies.

It was these studies that helped him formulate his most renowned piece of work. Rather than sticking to the rigidity of physics that pervaded at the time, namely the study only of physical matter, Newton began to envision an invisible force that had an effect on everything. It is often said that earlier in 1666 he saw an apple fall from a tree and quickly formulated his theories of gravity. In actuality, however, it was almost two decades of work that allowed him to appreciate the importance of this force.

An interchange of letters with Hooke regarding planetary motion ironically helped Newton formulate his thoughts into a capable theory. In 1686 he consolidated his work into a series of three books known as *Philosophiæ Naturalis Principia Mathematica* (*Mathematical Principles Of Natural Philosophy*). They stated his now famous laws of motion and universal gravitation, in addition to forming the foundation of classical mechanics on which modern physics and calculus is now based. His work was astounding in its breadth and depth.

Newton would continue to be hounded by Hooke until the latter's death in 1703, after which Newton was elected president of the Royal Society. In the following year he published his second major work, *Opticks*, which analysed the nature of light. In it he described the diffraction and refraction of light by lenses and prisms.

Newton lived most of the remainder of his days in London until his death in Cranbury Park, near Winchester, on 20 March 1727. Having contended with hardship his whole life, he was finally able to reap power and success from his groundbreaking work, albeit with bullish tactics while heading the Royal Society. Nonetheless, he is regarded as one of the greatest scientific minds to have lived, and his work continues to form the basis of our efforts to further understand the universe. ■

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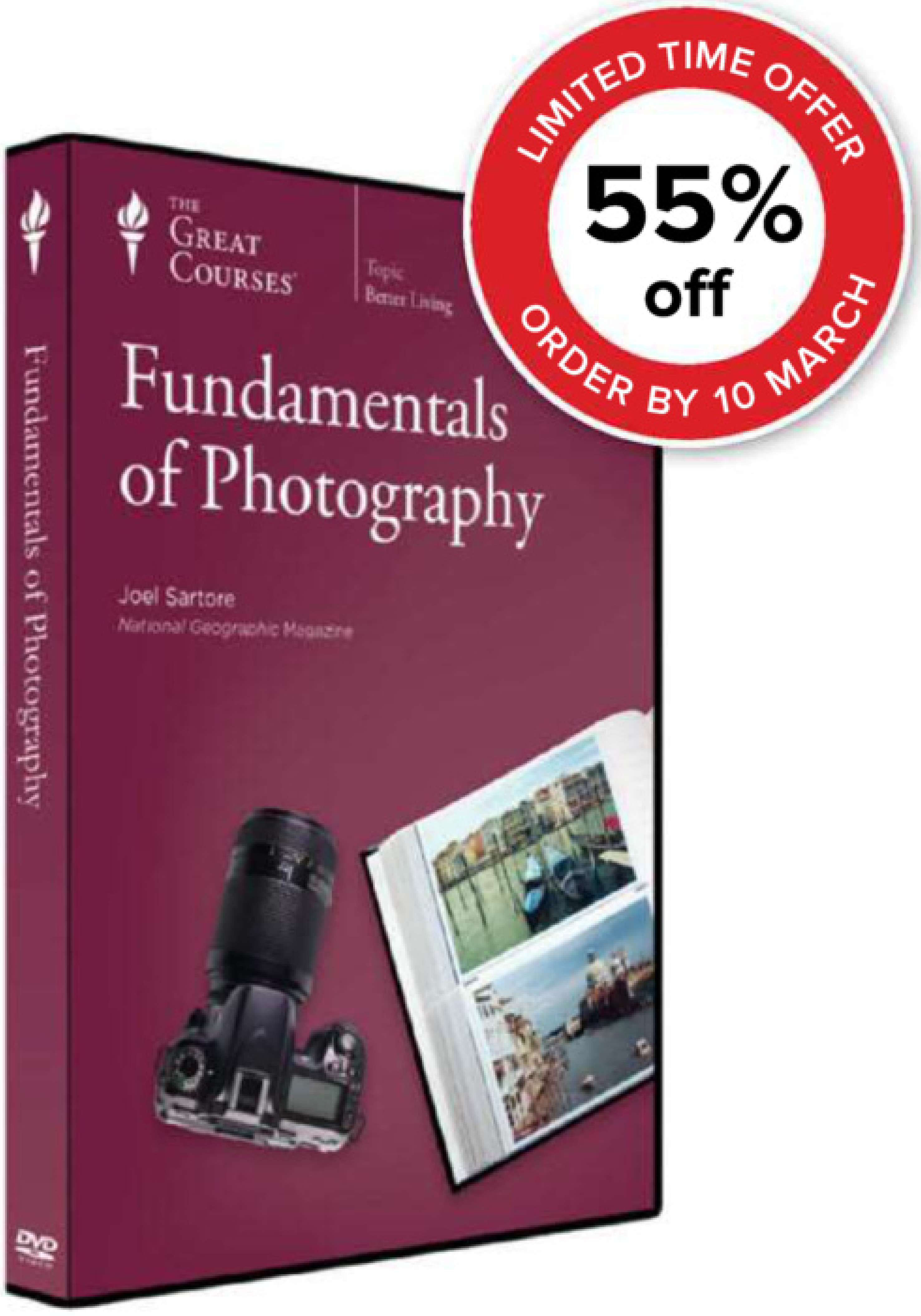

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